University of Tehran Press

Online ISSN: 2345-475X

DESERT

Home page: https://jdesert.ut.ac.ir/

Linear Dunes: Morphology from Google Earth

Andrew S. Goudie

Oxford University School of Geography and the Environment, South Parks Road, Oxford, OX1 3QY, United Kingdom. Email: andrew.goudie@stx.ox.ac.uk

Article Info.

Article type:
Research Article

Article history:
Received: 04 Oct. 2023
Accepted: 27 Oct. 2023
Published online: 27 Dec. 2023

Keywords:
Linear dunes,
Tuning forks dunes,
Star dunes,
Dome dunes,
Barchans parabolics,
Zibars.

ABSTRACT

Linear dunes are widespread in the Earth's deserts and also in some extraterrestrial locations such as Titan and Mars. They show great variety in their forms, and occur in three main classes: simple, compound and complex. Using Google Earth this paper illustrates this diversity. Among the topics covered are simple dunes, linear dunes with tuning fork junctions, linear dunes with complex crests, linear dunes associated with stars, with domes, with zibars, with barchans and with parabolics, and linear dunes controlled by topography.

Cite this article: Goudie, A.S. (2023). Linear Dunes: Morphology from Google Earth. DESERT, 28 (2), DOI:10.22059/jdesert.2023.95482

1. Introduction

Over the years there have been many attempts to classify desert dune forms and to describe their morphologies in different parts of the world. For instance, Tsoar et al. (2004) classified them into three main types: migrating dunes (which include transverse ridges, barchanoid ridges, barchans, etc.), elongating dunes (exemplified by the various types of linear dune discussed in this chapter), and accumulating dunes (exemplified by star dunes). In addition, there are anchored or impeded dunes, which are fixed in position by topography (e.g. climbing and falling dunes, lunettes in the lee of playa basins, and linear dunes downwind of obstacles), by buildings (e.g. shadow dunes) or by vegetation (e.g. nebkhas and parabolic dunes).

Linear dunes are straightish ridges with slip faces on both of their sides that run more or less parallel to the resultant drift direction under the long-term influence of prevailing sand-shifting winds. Linear dunes generally occur in loose sand in areas where there is a bimodal wind regime and where sand supply is relatively high. However, Rubin and Hesp (2009) recognized that some linear dunes develop where there is a unimodal wind blowing over sediment that is at least partially stabilized by upwind obstacles - 'lee dunes' or 'sand-shadow dunes' - and dunes stabilized by vegetation, including trailing arms of parabolic dunes.

They are one of the most widespread dune types, occurring not only in all major sand seas on Earth but also on extra-terrestrial bodies such as Saturn's moon, Titan, Venus and Mars (see, for example, Edgett and Blumberg, 1994; Lancaster, 2006). They also have a low ratio of dune to inter-dune areas. The spacing between ridges generally increases with increasing dune size. Linear dunes are also sometimes called sand ridges or longitudinal dunes, but linear dune is now the preferred term, partly because it has no genetic connotations. They often, though not invariably, have a sharp crest which explains why they are sometimes called *seif* (a sword) in Arabic. They may also display a meandering or sinuous tendency (Tsoar, 1983). The ridges may link together in tuning-fork-shaped junctions (Goudie, 1969) that almost invariably point downward and may have a similar dendritic pattern to that recognised in stream systems. Their large mass means that they are relatively stable features and this stability often encourages the growth of vegetation on their surfaces, even in quite arid areas. Their mass also enables them to persist for long periods, even through major climatic fluctuations (Wiggs, 2019).

The Kalahari is notable for the predominance of linear dunes (c 86%), a characteristic that it shares with the Australian deserts, such as the Simpson and the Great Sandy, while the Ala Shan of Central Asia, which lies between the Tibetan Plateau and the Altai Mountains in Mongolia, has very few. In the Thar of India, linear dunes only represent around 7.5 % of all aeolian landforms (Srivastava *et al*., 2019). Pye and Tsoar (1990) gave a mean figure of 42.7% for the relative percentage that linear dunes make up in the world's ergs.

Regional differences in form occur. Bullard *et al.* (1995) described the various dune forms that occur in the south west Kalahari, while Edgell (2006) describes the range of linear dunes in different parts of Arabia. There is also considerable morphological variability in linear dune types in Australia, where substrate type and sand supply are crucial controls (Fitzsimmons, 2007). Hesse (2011, p. 315) has argued that dune patterns in Australia suggest that 'under wind conditions suitable for the formation of longitudinal dunes low local sand supply will lead to short dunes (many terminations) and higher local sand supply will lead to long/continuous dunes (few terminations). Increasingly more variable winds (seasonally or over longer timescales) will lead to dendritic forms and eventually to network dunes formed of numerous straight segments. Under extreme conditions of low local sand supply and highly variable wind direction, mounds form; a counterpart to the star dunes formed under very high sand supply'. Also in Australia, Wasson *et al.* (1988) found that the most closely spaced dunes (<300 m on average) form on finer sediments, whereas the widely spaced dunes (>600 m on average) often lie on a coarse-grained substrate rich in gravel, a substrate that tends to occur both around the edges of the dunefields and at slightly higher elevations than the finer sediments beneath the closely spaced dunes. The importance of underlying topography in controlling dune spacing, orientation, etc. in Central Australia is demonstrated by Fischer *et al.*, (2023).

Some linear dunes may have modest heights (ten to twenty metres) and spacing (a few hundreds of metres) but others can have heights in excess of 150 m, and a spacing of one or two km. These are among the biggest dunes in the world. Examples of the former are the dunes of Australia and the Kalahari, whereas examples of the latter are the dunes of the central Namib or those of the Rub' al Khali in Arabia. The Rub' al Khali Desert has individual dunes, locally termed *'uruq*, that may be over 250 km – 500 km long (Edgell, 2006, p129; Xiao *et al.*, 2021), and 500 m wide.

McKee (1979) and Breed and Grow (1979) undertook a global survey of dune types, primarily based on remote sensing imagery, and recognised three main categories of linear dunes. These were (1) simple, (2) compound and (3) complex forms. Breed and Grow (p. 261) described simple dunes as 'single or bifurcated ridges with narrow crests that may be sharp or subdued but which do not have slipfaces or secondary dunes developed upon them.' Compound linear dunes were described as 'broader linear ridges that have relatively smaller linear ridges, each with its own slipfaces, on their tops'. They specifically mentioned 'feathered' compound dunes where subsidiary ridges intersect or spread obliquely from the main ridge. They described complex linear dunes as 'narrow or broader linear ridges that have other dune types, such as star, dome-shaped, and barchan (crescentic) dunes, superimposed upon them'. Identification of patterns of different linear dune types is now being facilitated by various new geospatial techniques (Fischer et al., 2023).

Building on Breed and Grow's work, the purpose of this paper is to use Google Earth imagery to demonstrate some of the main forms that linear dunes have.

2. Simple linear dunes

Simple linear dunes are a widespread type of linear dune and they vary greatly in size. They display parallel ridges with very even spacing and with great lengths largely uninterrupted by junctions. Good examples occur in parts of Saudi Arabia, the Kalahari (Figure 1) and also in the Wahiba Sands of Oman (Goudie *et al.*, 1987). The spacing can be highly variable, with those in Saudi Arabia being up to 1.8 km apart, and those from the Kalahari being only c 300 m apart. However, a note of caution is required about simple dunes – as higher resolution remote sensing imagery becomes available, it is clear that many so-called simple dunes may, when looked at in detail, have complex crests.

Highly vegetated forms are relicts of past drier conditions and are known, for example, from the northern mega-Kalahari (Grove, 1969; Shaw and Goudie, 2002), from the Ancient Erg of Hausaland in northern Nigeria (Grove, 1958), and the *Qoz* of Kordofan (Grove and Warren, 1968).

3. Linear dunes with tuning fork junctions

Tuning fork dunes, some of which have a well-developed dendritic pattern, occur primarily in two Southern Hemisphere regions: the Kalahari of southern Africa (Goudie, 1969) and the sandridge deserts of Australia (Figure 2), but also in the Negev. Some linears have crests that divide and re-form like a series of chain links (Hesse, 2011) or beads (Scuderi, 2019), (Figure 3) while some, as in Yemen, have complex crests with tuning fork forms on their surfaces. The Australian chain crest longitudinal dunes strongly resemble series of blowouts, which may have developed because of local vegetation depletion and sand reactivation. Indeed, the state of vegetation cover can be very important and Tsoar and Møller (1986) showed in the Negev that the destruction of vegetation cover over a linear vegetated dune could lead to dynamic, braided shapes.

4. Linear dunes associated with stars

If winds come from many different directions, star dunes (or *rhourds*), with three or more arms extending radially from a central peak, occur (Figure 4). Each arm has a steep-sided, sinuous crest, with avalanche faces. Star dunes, which occur on Mars and Titan, are widespread in Earth's drylands and Goudie *et al.* (2021a), based on an analysis of Google Earth images, identified and characterised 25 provinces where they occur, including those in East Asia, Western Asia, the Americas, southern Africa and northern Africa. Star dunes are more or less absent in inland Australia, the Kalahari, Indian sand seas, and in the southern Sahara. The stars may either occur as groups in a line or as forms on the top of ridges. The latter type is the most common.

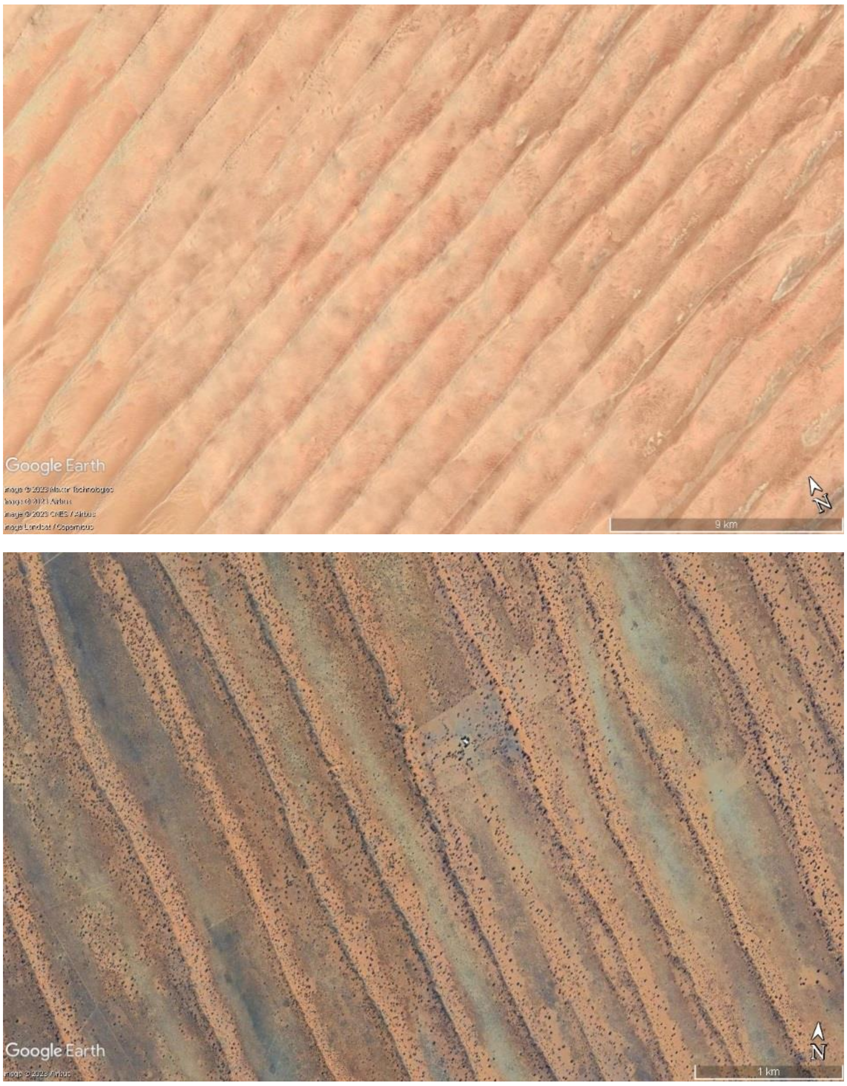

Fig. 1. Simple linear dunes. Top: in Saudi Arabia. Location: 18°49'58.57''N, 49°36'34.76''E. Scale bar is 9 km. Dunes are c 1.8 km apart. Bottom: in the Kalahari. Location: 25° 3'45.82'', 19°14'34.88''E. Scale bar is 1 km. Dunes are c 300 m apart. ©Google Earth.

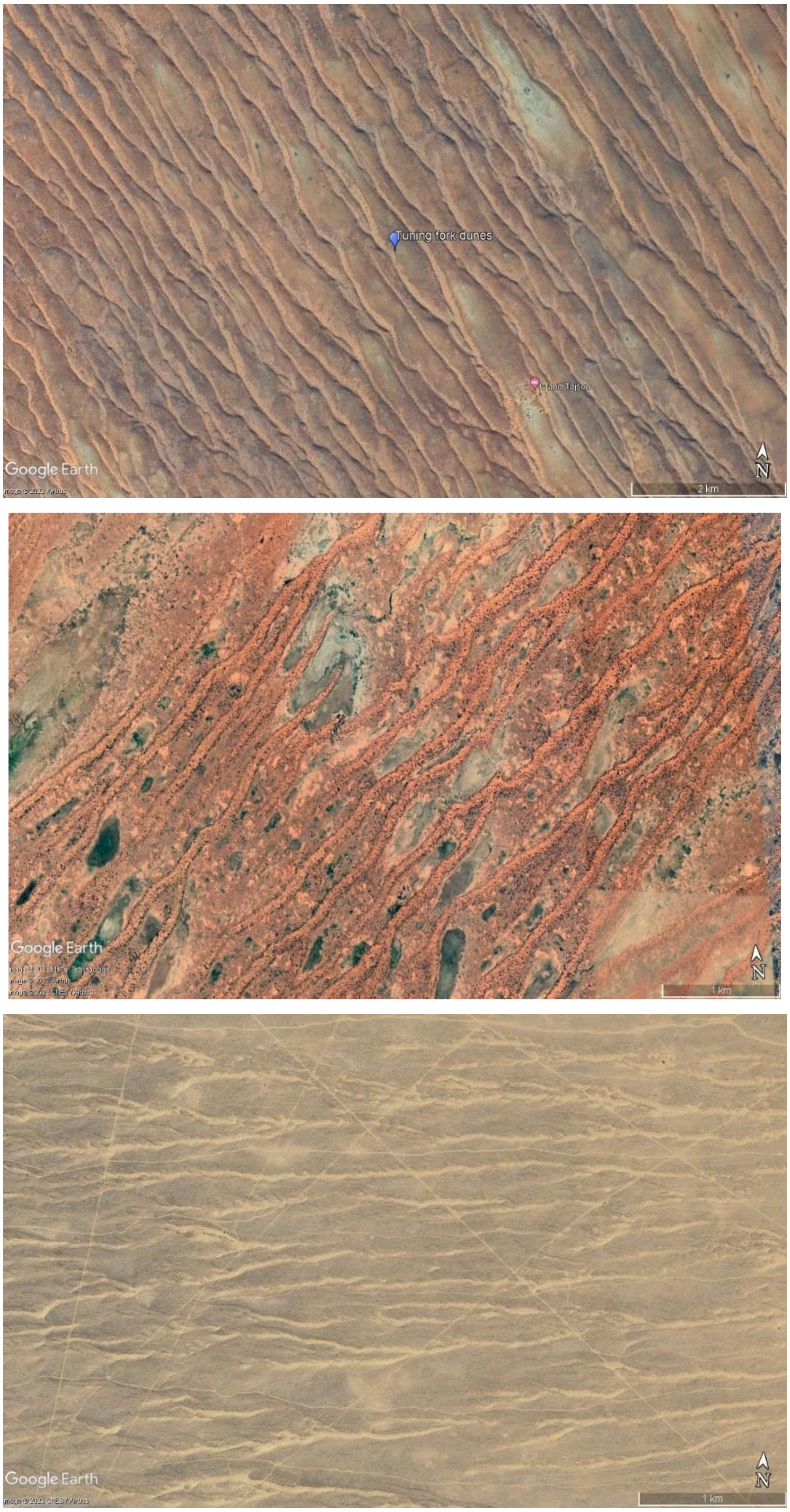

Fig. 2. Tuning fork dunes. Top: in the southwest Kalahari. Location: 25°51'32.18"S, 19°37'29.12"E. Scale bar is 2 km. Middle: broad-crested examples in SE Australia. Location: 29°31'55.52"S, 140°31'24.20"E. Scale bar is 1 km. Bottom: in the Negev. Location: 31° 5'35.68"N, 34°25'44.31"E. Scale bar is 1 km. ©Google Earth.

Fig. 3. Tuning fork dunes with beaded crests in the Great Sandy Desert of Australia. Location: 20°46'27.16"S, 122°33'18.85"E. Scale bar is 1 km. ©Google Earth.

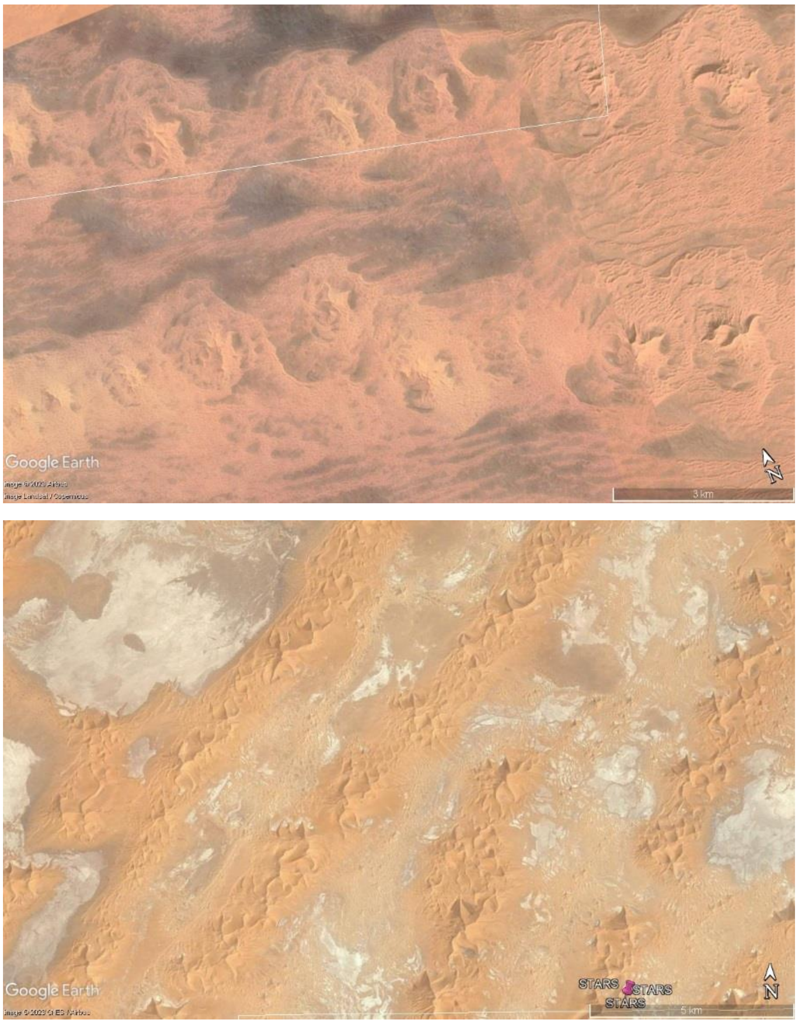

Fig. 4. Linear dunes and star dunes. Top: Lines of star dunes in the Ad Dahna of Saudi Arabia. Location: 26°31'15.63"N, 45°59'27.48"E. Scale bar is 3 km. Bottom: Linear dunes capped by star dunes, Grand Erg Occidental, Algeria. Location: 27°51'45.22"N, 4° 9'4.14"W. Scale bar is 5 km. ©Google Earth.

5. Linear dunes associated with domes

Dome dunes (Goudie *et al.*, 2021b) are mounds of sand that generally, though not invariably, lack external slip faces. There are two main types. Mini-domes are typically just a few metres in height and some tens of metres across. Some of these may either be proto- or degraded barchans and the two forms occur in close proximity (Zhang *et al.*, 2021). Mega-domes, on the other hand, are tens of metres high and hundreds of metres in width. In Africa, they are found in the Grand Ergs Occidental and Oriental, the Murzuk and Ubari sandseas of Libya, the Qattara Depression of Egypt, and the Red Sea Province of Sudan. In Asia they occur in the Nefud of Saudi Arabia, the Rub' al Khali, and the Taklimakan and Wulanbuhe Deserts of China (Qian *et al.*, 2020).

Linear dunes associated with domes have two forms (Fig. 5). One of these consists of lines of relatively discrete domes forming a chain, as shown in the Rub 'Al Khali and the Nafud al Mazhur in Saudi Arabia (Edgell, 2006, figure 8.6). Alternatively, they can occur as linked up forms, with individual domes joined up by a linear ridge, as shown in the Taklamakan Desert of China.

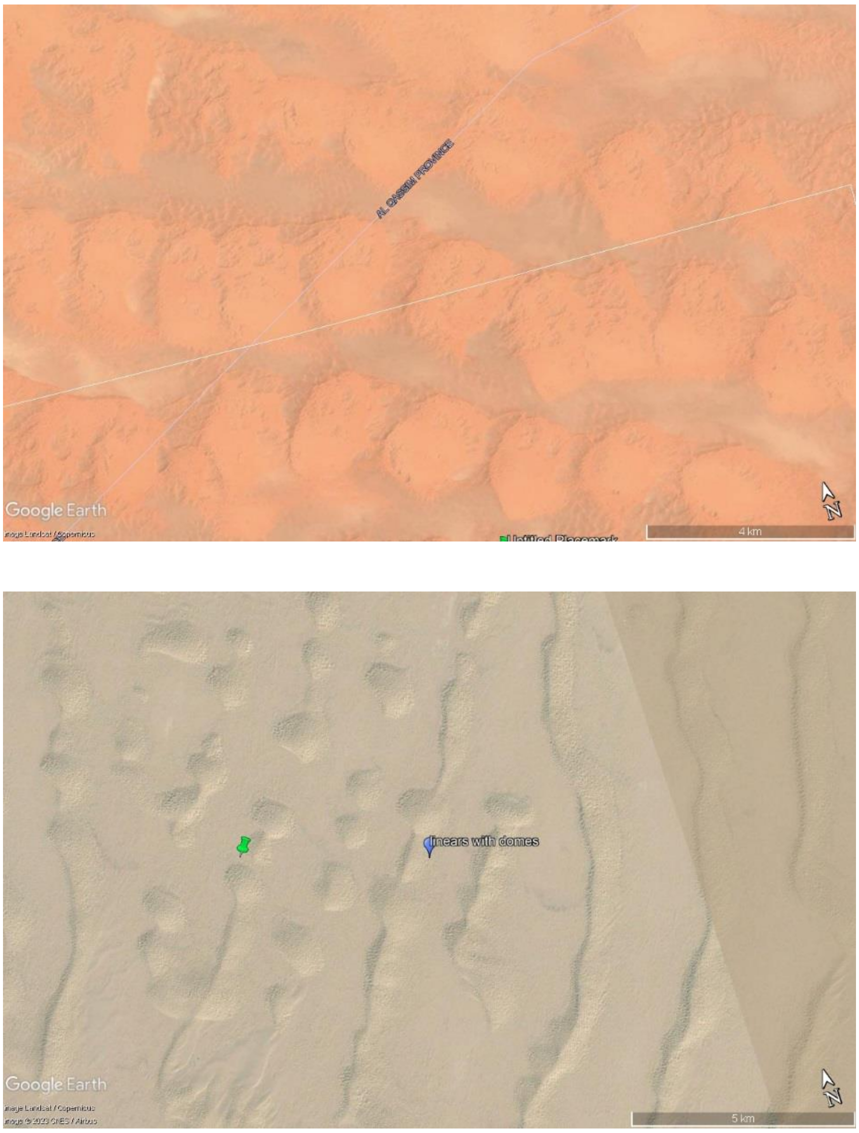

Fig. 5. Dome dunes and linear dunes. Top: Domes in lines, Saudi Arabia. Location: 26°59'54.85"N, 44°36'15.75"E. Scale bar is 4 km. Bottom: Linear domes China. Location: 40°15'14.24"N, 84°31'7.69"E. Scale bar is 5 km. ©Google Earth.

6. Linear dunes with complex crests

Large linear dunes may display a wide range of micro-forms on their surfaces. These include sinuous linear ridges, oblique linear ridges, and honeycomb structures (Figure 6). Improved higher resolution remote sensing techniques have often revealed such features, which were not, for example, visible on early Landsat images (Zheng et al., 2022).

Breed and Grow (1979) referred to 'feathered' dunes and these were recognized by Mainguet (1984, p. 43) as a major type of composite dune. She termed them *bouquet* dunes. Examples are known, *inter alia*, from south west Yemen, the Great Sand Sea in Egypt, and from the northern part of the Wahiba Sands in Oman (Goudie *et al*., 1987). Small linear dunes join a mega-ridge at an oblique angle (Figure 7).

Complex linear dunes can on occasion have barchanic ridges superimposed upon them. This is the case in the Sahara in western Algeria (Figure 8) (Hu *et al*., 2021).

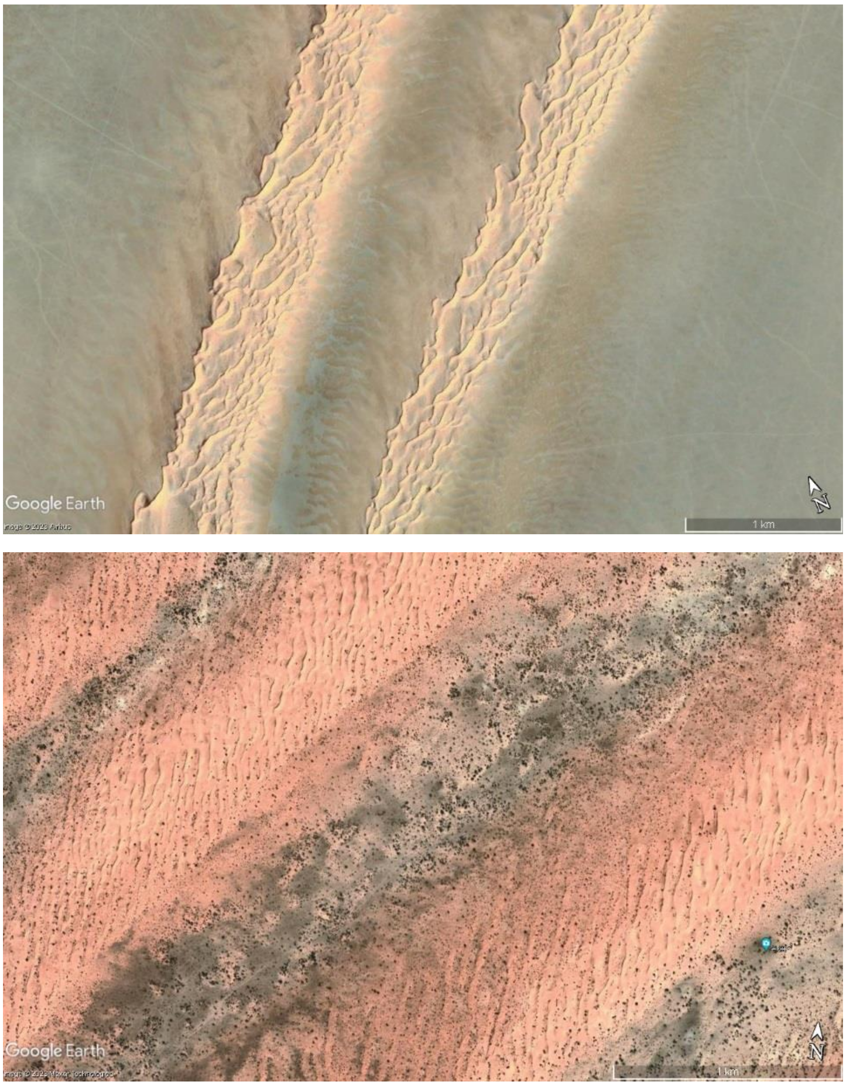

Fig. 6. Linear dunes with complex crests. Top: Mega-dunes with complex crests consisting of small linear ridges, Yemen. Location: 16°36'52.62"N, 45°45'58.16"E. Scale bar is 1 km. Middle: Large linear dunes with strongly oblique ridges crossing them, Mauritania. Location: 17°59'18.32"N, 15°14'34.39"W. Scale bar is 1 km. Bottom: Linear dunes capped with honeycomb structures in the Taklamakan Desert of NW China. Location: 39°47'16.04"N, 83° 3'0.65"E. Scale bar is 2 km. ©Google Earth.

Fig. 6. Continued

7. Linear dunes associated with zibars

Linear dunes are quite frequently found in close proximity to zibars which not only develop in interdune areas but along dune flanks (Figure 9). Zibars are defined as 'coarse-grained, low relief, slipfaceless, eolian bedforms that occur on sand sheets and within interdune corridors of many eolian sand seas' (Nielson and Kocurek, 1986, p. 1). They have fairly regular spacings of up to 400 m, a maximum relief of less than 10 m, and form an undulatory surface. Zibar stoss-slope and lee-slope angles are generally less than 5^{o} and 15^{o} respectively. Examples are reported from the Tenéré Desert in the Sahara, Algeria, Mauritania, Saudi Arabia, Sinai, the Namib, the Kumtagh Desert of China, and the Algodones dunes in south east California, USA. Details and images of zibars with linear dunes are given in Goudie (2023) and in Edgell (2006, p. 133). They tend to be transverse to the modern prevailing wind and many, but not all, are straight in plan form. The sediments that form them are coarse in comparison to normal dune sand and this coarseness may be one of the primary factors that suppresses slipface formation. Some zibars are made of granules up to 2000 µm in diameter, whereas most dune sand is a tenth of that size.

Tsoar and Yaalon (1983) described from the Negev a case where a zibar became transformed into a linear dune.

8. Linear dunes associated with barchans

Bagnold (1941), who worked in the Libyan Desert, argued that linear dunes could form from barchans that became deformed as they moved into a regime which had less unimodal winds. This undoubtedly happens in local situations, but scarcely seems a model that can apply, for example, in Australia, where linear dunes are nearly ubiquitous but barchans are almost absent. Indeed, one can find examples where the reverse occurs, with barchans developing from linear dunes. Radebaugh *et al.* (2010) illustrate the elongation of linear dunes from barchans on Earth (the Namib) and from Titan, while Lancaster (1980) found evidence for the applicability of the Bagnold model in the Namib. Examples from the Libyan Desert and Iran are shown in Figure 10. In Figure 11, tadpole-shaped dunes from Mauritania are shown. The Bagnold model is not the only one to explain asymmetric barchans and their elongation into linear dunes and other models involving changes in wind flow patterns also need to be considered (Bourke, 2010; Lv et al., 2016; Tsoar and Parteli, 2016). Linear dunes and mega-barchanoid dunes appear to co-exist in the Thar Desert (Kar, 1990). In the Kumtagh Desert of China, 'raked dunes' are another form showing barchanoid elements formed on, and perpendicular to, linear dunes (Dong *et al*., 2010) (Figure 12).

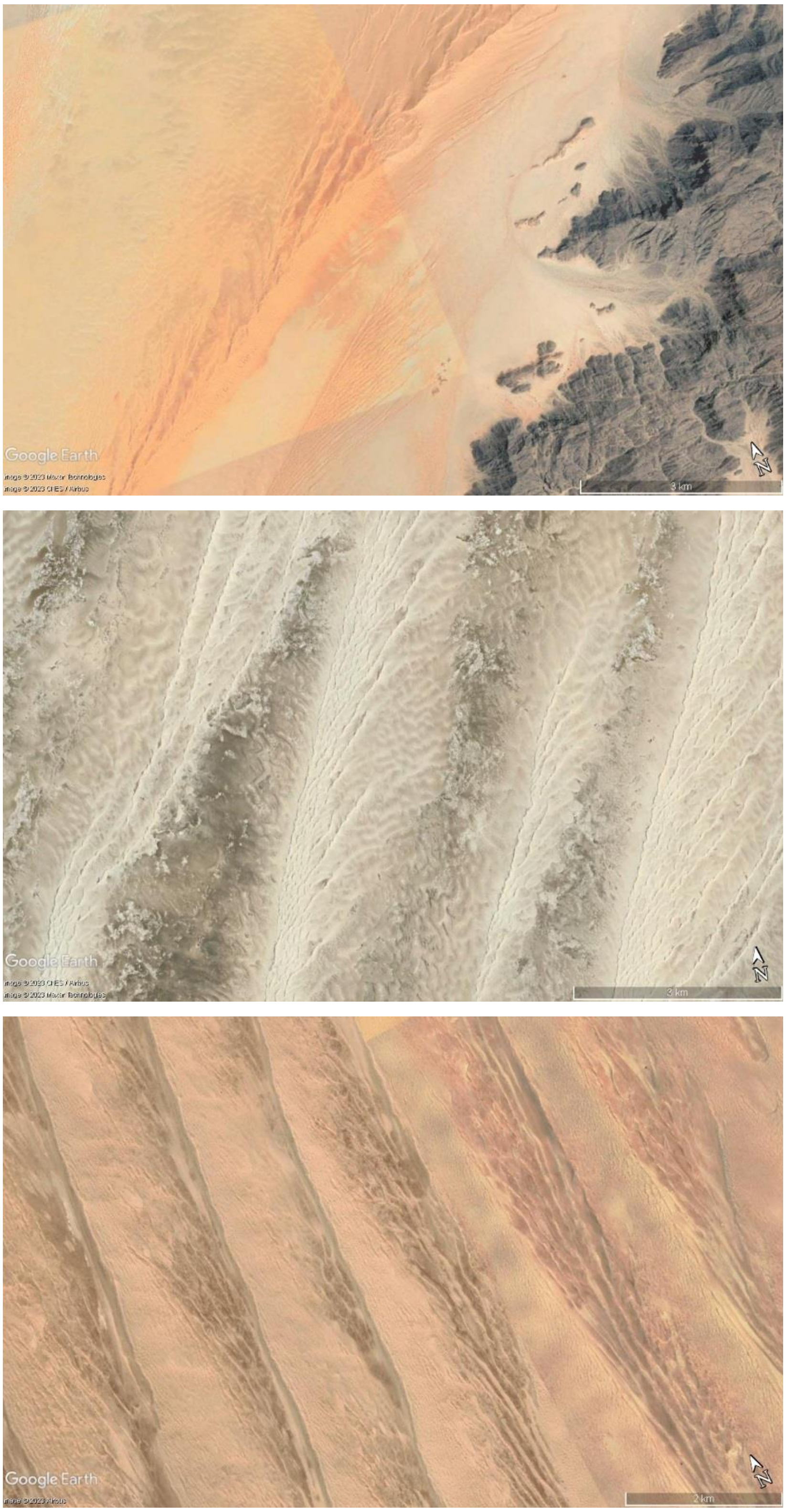

Fig. 7. Feather dunes. Top: in Yemen. Location: 16°43'21.02"N’ 45°15'32.72"E. Scale bar is 3 km. Middle: in the Great Sand Sea Egypt. Location: 27°17'44.07"N, 20°17'42.57"E. Scale bar is 3 km. Bottom: in the Wahiba Sands, Oman. This site is described by Pye and Tsoar (1990, p. 180) as consisting of a ‘Complex asymmetric megadune with superimposed seif dunes’. Location: 22° 0'53.75"N, 58°50'34.65"E. Scale bar is 2 km. ©Google Earth.

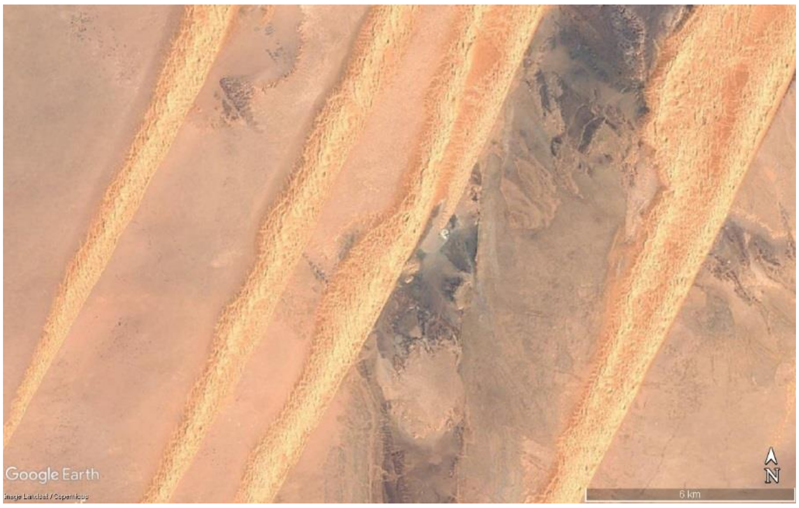

Fig. 8. Complex linear dunes in western Algeria with barchanoid ridges on their crests. Location: 25°31'38.05"N, 2°36'26.20"W. Scale bar is 6 km. ©Google Earth.

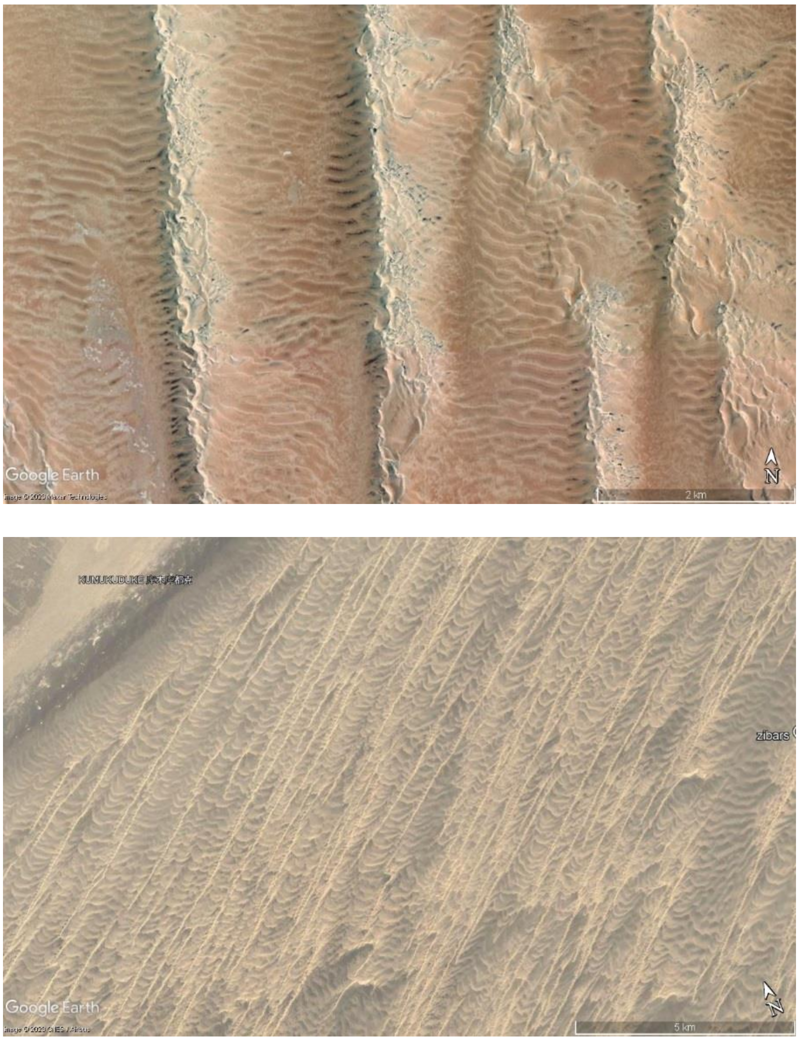

Fig. 9. Zibars between and abutting linear dunes. Top: in Namibia. Location: 23°51'40.04"S, 14°53'40.54"E. Scale bar is 2 km. Bottom: in China. Location: 40° 9'26.35"N, 91°56'42.51"E. Scale bar is 5 km. ©Google Earth.

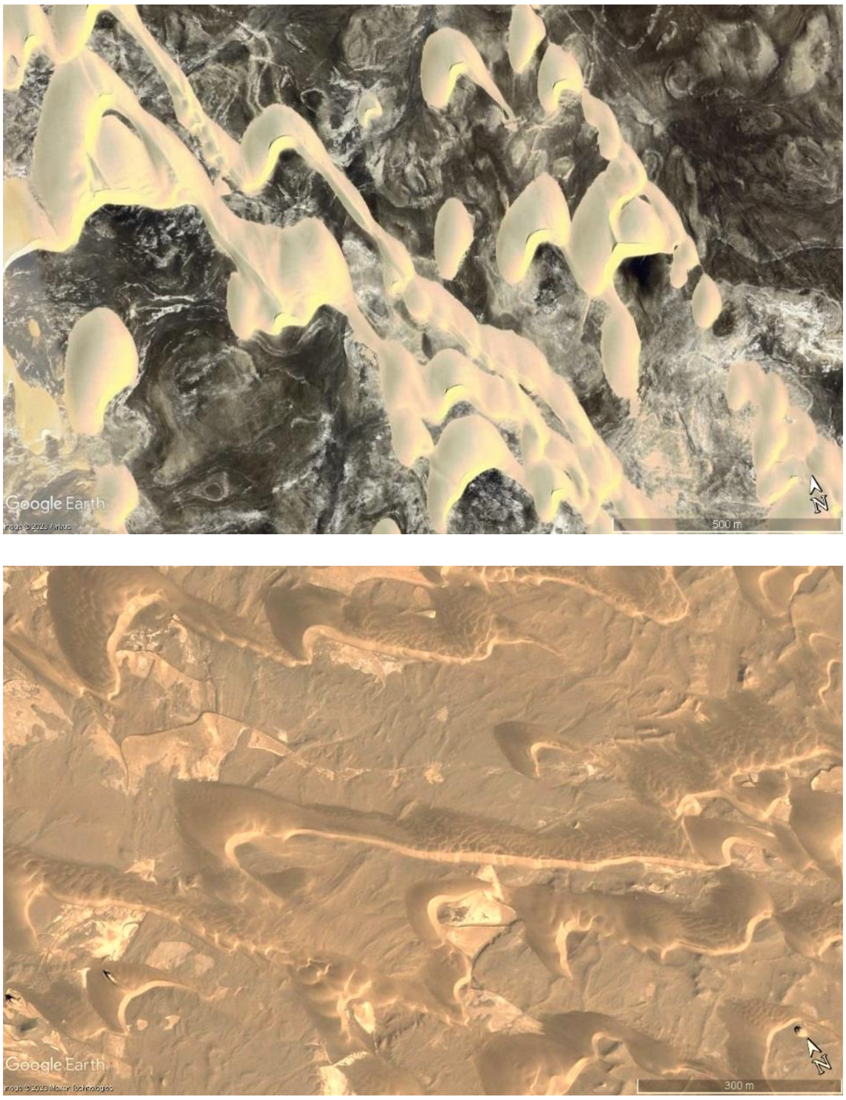

Fig. 10. Barchans transforming into linears. Top: in the Libyan Desert of Egypt as per the Bagnold (1941) model. Location: 26°34'26.58"N, 30° 5'8.92"E. Scale bar is 500 m. Bottom: in Iran. Location: 30° 1'57.14"N, 58° 5'51.16"E. Scale bar is 300 m. ©Google Earth.

9. Linear dunes associated with parabolics

A class of dune in which the form owes much to the presence of a limited vegetation cover or some soil moisture is the parabolic dune (Goudie, 2011; Vimpere *et al.*, 2021). These are hairpin-shaped with the nose pointing downwind. They may have a U-shaped or V-shaped form, with three basic features: a depositional lobe or nose on the downwind side, trailing arms or ridges, and a deflation basin between the trailing arms. The wind regimes associated with parabolic dunes are generally regarded as being unimodal or acute bimodal.

Verstappen (1970) proposed that some linear dunes in the Thar Desert evolved from parabolic dunes. This can also be seen in the Tusayan dunes of the Moenkopi Plateau in Arizona.

The Thar Desert in Rajasthan, India, and neighbouring parts of Pakistan, probably has the largest extent of parabolic dunes in the world (Allchin et *al.*, 1978). Precipitation levels are today relatively high (c 200-400 mm) and the area has a not inconsiderable vegetation cover, and large areas are cultivated. The dunes have a southwest to northeast orientation (Kar, 1993) and have probably been moulded by the south west monsoon winds in early summer. These parabolic dunes form a clustered 'rake-like' appearance with longer arms in the middle of the parabolic cluster and gradually shorter arms on each side (Figure 13). The arms can be up to 2500 m long, with inter-arm spacing ranging between 150 m and 650 m. The nose may be as much as 10-70 m high. Luminescence-based chronology shows that the parabolic dunes in the region accumulated during late Pleistocene-Early Holocene (Srivastava *et al.*, 2019).

Fig. 11. Linear tadpole-shaped dunes in Mauritania. Location: 20°57'24.06"N, 16°47'6.20"W. Scale bar is 500 m. ©Google Earth.

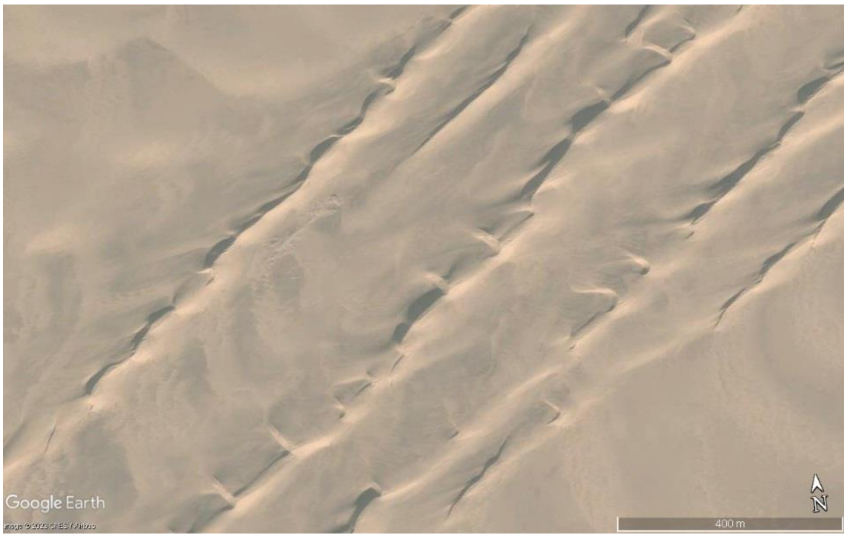

Fig. 12. 'Raked' linear dunes in the Kumtagh Desert, China, showing barchanoid forms perpendicular to the linear ridges. Location: 40°13'22.98"N, 92°11'3.70"E. Scale bar is 400 m. ©Google Earth.

10. Linear dunes associated with topography

One preferential location for the development of a linear dune is downwind of an obstacle. Mainguet (1984) called these dunes of *sillage* (similar to the bow wave in the wake of a boat), formed by the deposition of sand tangentially to the wind vortices formed downwind of an obstacle. They are common in the lee of escarpments and rock outcrops in the Libyan Desert

(Figure 14). They are in a sense comparable to the shadow dunes that occur in the lee of nebkhas (Goudie, 2022). They are relatively short features and often have a dagger like form. Pye and Tsoar (1990, fig. 6.10) illustrate similar lee dunes downwind of an escarpment in northern Sinai. Such dunes may break up and feed chains of barchans downwind.

Other linear dunes may form downwind of closed basins and their neighbouring lunettes, as is the case in the south west Kalahari (Lancaster, 1988) (Figure 15). Linear dune forms may also be modified by the presence of valleys (Bullard and Nash, 1998) and by regional slopes, as in the Great Sandy Desert of Australia (Telfer *et al*., 2019).

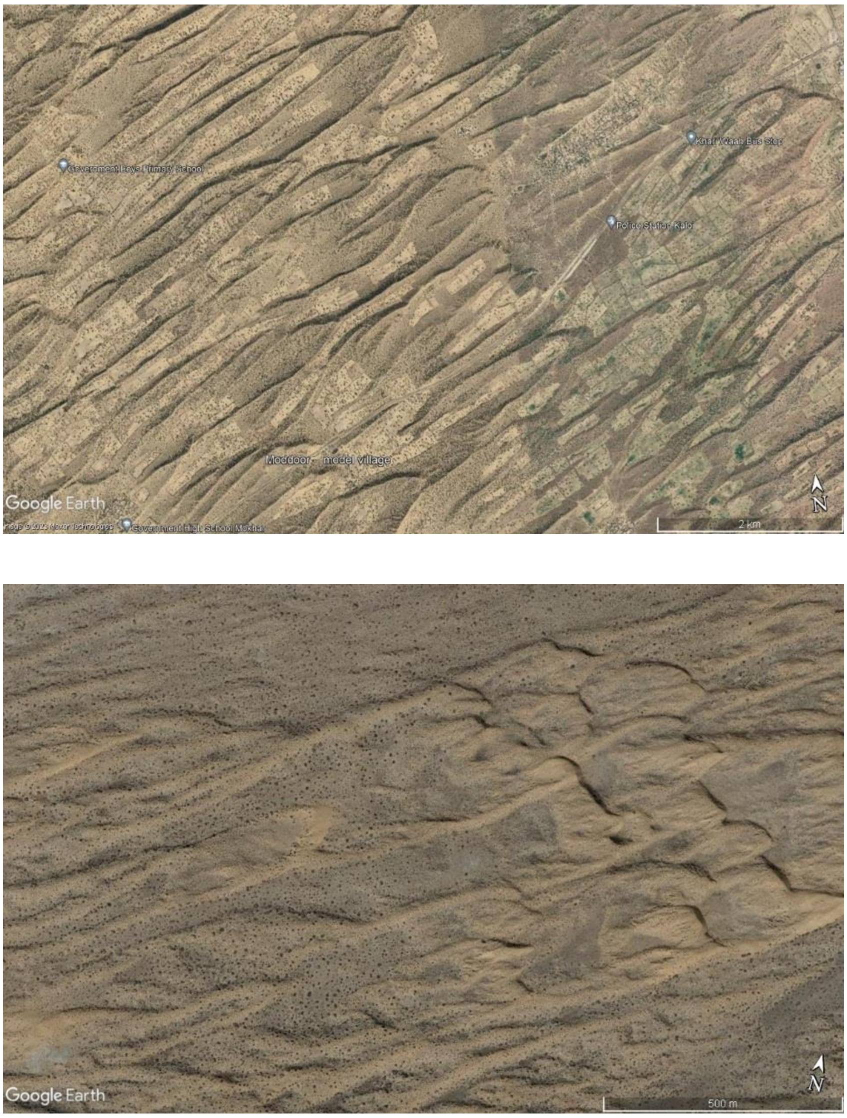

Fig. 13. Linear dunes derived from parabolics. Top: Linear dunes consisting of the long trailing arms of parabolic dunes in the Thar Desert of NW India. Location: 24°45'38.48"N, 69°43'28.95"E. Scale bar is 2 km. Bottom: Linear dunes consisting of the long trailing arms of parabolic dunes in northern Arizona, USA. Location: 36°13'51.89"N, 111° 7'55.58"W. Scale bar is 500 m. ©Google Earth.

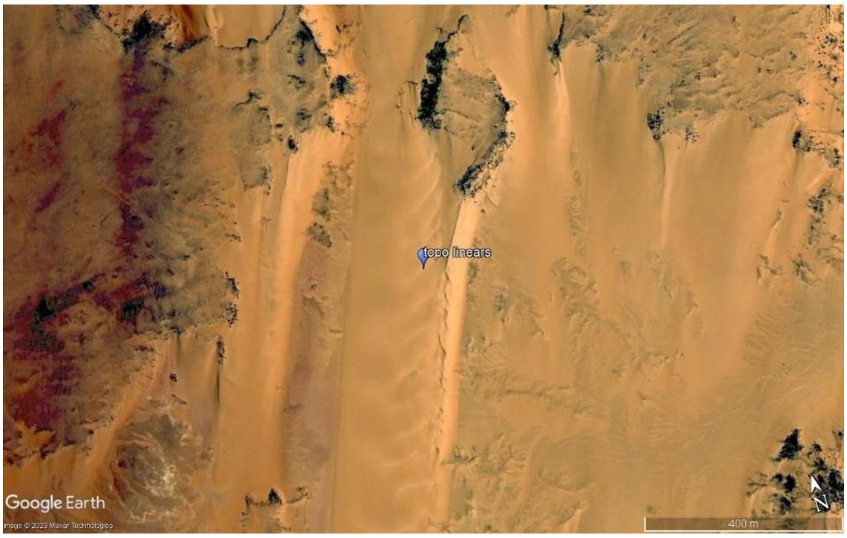

Fig. 14. Topographic linear dunes 19°41'50.51"E in Egypt. Location: 19°53'20.69"N, 28° 8'47.38"E. Scale bar is 400 m. ©Google Earth.

Fig 15. Linear dunes forming downwind from Koes Pan, Namibia. Clusters of small dunes in a network of irregular shapes gradually become more regular downwind (i.e. to the south west). Location: 26°20'48.33"S, 19°41'50.51"E. Scale bar is 4 km. ©Google Earth.

11. Conclusions

Using Google Earth images, this paper has demonstrated that linear dunes have a very wide range of morphologies. There are simple forms and compound forms (which are broader ridges that have relatively smaller linear ridges, each with its own slipfaces, on their tops). These include 'feathered' and 'raked' compound dunes where subsidiary ridges intersect or spread obliquely from the main ridge. Complex linear dunes are linear ridges that have other dune types, such as star, dome-shaped, and barchan (crescentic) dunes, superimposed upon them. Linear dune forms are also sometimes determined by their derivation from either barchans or parabolic dunes, and also by various topographic factors, such as the presence of escarpments, playa basins, river valleys, and regional slopes. General explanations for the diversity of forms may include differences in wind regimes, vortices, and seasonality, and variations in vegetation cover and substrate, but these still warrant further investigation. Hesse (2011) stressed the importance of vegetation cover and a relatively humid climate in Australia. Here areas of dunefield often have crests that are very broad. This morphology possibly results from long-term degradation of the dune form by surface wash and soil erosion processes. There is evidence for reworking of dune crests, with shallow mobile sand patches and small slip faces, or series of blowouts on dune crests. Many dunes, even in the most arid parts of the desert, show evidence of water erosion in the form of rills, gullies or topsoil erosion. Degraded forms with wide crests also occur in Ngamiland, Botswana (McFarlane et al., 2005). Linear dunes will also have gone through climatic changes and so may show more than one phase of activity evident in their morphology. This is the case, for example, in Mauritania, where there are three generations of dunes (Lancaster *et al*., 2002), and in the United Arab Emirates where younger, small ridges, occur on older mega-ridges (Atkinson *et al*., 2012). The use of OSL dating makes this an increasingly fertile source of research.

References

Allchin, B., A.S. Goudie, K.T.M. Hegde, 1978. The Prehistory and Palaeogeography of the Great Indian Desert. Academic Press, London, p. 389.

Atkinson, O.A., D.S. Thomas, A.S. Goudie, A.G. Parker, 2012. Holocene development of multiple dune generations in the northeast Rub'al-Khali, United Arab Emirates. The Holocene, 22(2); 179-189.

Bagnold, R.A., 1941. The Physics of Blown Sand and Desert Dunes. Methuen, London, p. 265.

Bourke, M.C., 2010. Barchan dune asymmetry: Observations from Mars and Earth. Icarus, 205(1); 183-197.

Breed C.S., T. Grow, 1979. Morphology and distribution of dunes in sand seas observed by remote sensing. USGS Professional Paper, 1072; 253-302.

Bullard, J.E., D.J. Nash, 1998. Linear dune pattern variability in the vicinity of dry valleys in the southwest Kalahari. Geomorphology, 23(1); 35-54.

Bullard, J.E., D.S.G. Thomas, I. Livingstone, G.F.S. Wiggs, 1995. Analysis of linear sand dune morphological variability, southwestern Kalahari Desert. Geomorphology, 11; 189-203.

Dong, Z., Z. Wei, G. Qian, Z. Zhang, W. Luo, G. Hu, 2010. "Raked" linear dunes in the Kumtagh Desert, China. Geomorphology, 123(1-2); 122-128.

Edgell, H.S., 2006, Arabian Deserts. Nature, Origin and Evolution. Springer, Dordrecht, p. 592.

Edgett, K.S., D.G. Blumberg, 1994. Star and linear dunes on Mars. Icarus, 112(2); 448-464.

Fischer, L.M., C. Sommer, K.E. Fitzsimmons, 2023. An open-source GIS approach to understanding dunefield morphologic variability at Kati Thanda (Lake Eyre), central Australia. Frontiers in Earth Science, 11; p.1196244.

Fitzsimmons, K.E., 2007. Morphological variability in the linear dunefields of the Strzelecki and Tirari Deserts, Australia. Geomorphology, 91; 146-160.

Goudie, A.S., 1969. Statistical laws and dune ridges in southern Africa. Geographical Journal, 135; 404-406.

Goudie, A.S., 2011. Parabolic dunes: distribution, form, morphology and change. Annals of the Arid Zone, 50(3&4); 1-7.

Goudie, A.S., 2022. Nebkhas: An essay in aeolian biogeomorphology. Aeolian Research, 54; p.100772.

Goudie, A.S., 2023. Zibars: Distribution, morphology and environmental controls. Aeolian Research, 60; p.100854.

Goudie, A.S., A.M. Goudie, H.A. Viles, 2021a. The distribution and nature of star dunes: A global analysis. Aeolian Research, 50; p.100685.

Goudie, A.S., A.M. Goudie, H.A. Viles, 2021b. Dome dunes: Distribution and morphology. Aeolian Research, 51; p.100713.

Goudie, A.S., A. Warren, D.K.C. Jones, R.U. Cooke, 1987. The character and possible origins of the aeolian sediments of the Wahiba Sand Sea, Oman. Geographical Journal, 153; 231-256.

Grove, A.T., 1958. The ancient erg of Hausaland, and similar formations on the south side of the Sahara. Geographical Journal, 124(4); 528-533.

Grove, A.T., 1969. Landforms and climatic change in the Kalahari and Ngamiland. Geographical Journal, 135(2); 191-212.

Grove, A.T., A. Warren, 1968. Quaternary landforms and climate on the south side of the Sahara. Geographical Journal, 134(2); 194-208

Hesse, P., 2011. Sticky dunes in a wet desert: formation, stabilisation and modification of the Australian desert dunefields. Geomorphology, 134(3-4); 309-325.

Hu, Z., X. Gao, J. Lei, N. Zhou, 2021. Geomorphology of aeolian dunes in the Western Sahara Desert. Geomorphology, 392; p.107916.

Kar, A., 1990. Megabarchanoids of the Thar: their environment, morphology and relationship with longitudinal dunes. Geographical Journal, 156; 51-61.

Kar, A., 1993. Aeolian processes and bedforms in the Thar Desert. Journal of Arid Environments, 25(1); 83-96.

Lancaster, N., 1980. The formation of seif dunes from barchans - supporting evidence for Bagnold’s model from the Namib Desert. Zeitschrift für Geomorphologie, NF 24; 160-167.

Lancaster, N., 1988. Development of linear dunes in the southwestern Kalahari, southern Africa. Journal of Arid Environments, 14(3); 233-244.

Lancaster, N., G. Kocurek, A. Singhvi, V. Pandey, M. Deynoux, J.F. Ghienne, K. Lô, 2002. Late Pleistocene and Holocene dune activity and wind regimes in the Western Sahara Desert of Mauritania. Geology, 30(11): 991-994.

Lancaster, N., 2006. Linear dunes on Titan. Science, 312; 702-703.

Lv, P., Z. Dong, C. Narteau, O. Rozier, 2016. Morphodynamic mechanisms for the formation of asymmetric barchans: improvement of the Bagnold and Tsoar models. Environmental Earth Sciences, 75; 1-9.

Mainguet, M., 1984. A classification of dunes based on aeolian dynamics and the sand budget. In: F. El Baz (ed.) Deserts and Arid Lands, Martinus Nijhoff, The Hague, pp. 31-58.

McFarlane, M.J., F.D. Eckardt, S. Ringrose, S.H. Coetzee, S.H., J.R. Kuhn, 2005. Degradation of linear dunes in northwest Ngamiland, Botswana and the implications for luminescence dating of periods of aridity. Quaternary International, 135(1); 83-90.

McKee, E. (ed), 1979. Global sand seas. United States Geological Survey Professional Paper 1052, p. 429.

Nielson, J.G. Kocurek, 1986. Climbing zibars of the Algodones. Sedimentary Geology, 48(1-2); 1-15.

Pye, K., H. Tsoar, 1990. Aeolian Sand and Sand Dunes. Unwin Hyman, London, p. 396.

Qian, G., Z. Yang, W. Luo, Z. Dong, J. Lu, M. Tian, 2020. Morphological and sedimentary characteristics of dome dunes in the northeastern Qaidam Basin, China. Geomorphology, 350; p.106923.

Radebaugh, J., R. Lorenz, T. Farr, P. Paillou, C. Savage, C. Spencer, 2010. Linear dunes on Titan and earth: Initial remote sensing comparisons. Geomorphology, 121(1-2); 122-132.

Rubin, D.M., P.A. Hesp, 2009. Multiple origins of linear dunes on Earth and Titan. Nature Geoscience, 2(9); 653-658.

Scuderi, L., 2019. The fingerprint of linear dunes. Aeolian Research, 39; 1-12.

Shaw, A.I., A.S. Goudie, 2002. Geomorphological evidence for the extension of the Mega-Kalahari into south-central Angola. South African Geographical Journal, 84(2); 182-194.

Srivastava, A., D.S.G. Thomas, J.A. Durcan, 2019. Holocene dune activity in the Thar Desert, India. Earth Surface Processes and Landforms, 44(7); 1407-1418.

Telfer, M.W., J. Radebaugh, B. Cornford, C. Lewis, 2019. Long-wavelength sinuosity of linear dunes on Earth and Titan and the effect of underlying topography. Journal of Geophysical Research: Planets, 124(9); 2369-2381.

Tsoar, H., 1983. Dynamic processes acting on a longitudinal (seif) sand dune. Sedimentology, 30(4); 567-578.

Tsoar H., J.T. Møller, 1986. The role of vegetation in the formation of sand dunes. In W.G. Nickling (ed.) Aeolian Geomorphology. Allken and Unwin, Boston, pp.75-95.

Tsoar, H., E.J. Parteli, 2016. Bidirectional winds, barchan dune asymmetry and formation of seif dunes from barchans: a discussion. Environmental Earth Sciences, 75: 1-10.

Tsoar, H., D.H. Yaalon, 1983. Deflection of sand movement on a sinuous longitudinal (seif) dune: use of fluorescent dye as tracer. Sedimentary Geology, 36(1); 25-39.

Tsoar, H., D.G. Blumberg, Y. Stoler, 2004. Elongation and migration of sand dunes. Geomorphology, 57; 293-302.

Verstappen, H.T., 1970. Aeolian geomorphology of the Thar Desert and palaeoclimates. Zeitschrift für Geomorphologie, NF12; 200-220.

Vimpere, L., S.E. Watkins, S. Castelltort, 2021. Continental interior parabolic dunes as a potential proxy for past climates. Global and Planetary Change 206:p.103622.

Wang, Z.T., Q.F. Sun, X.Z. Ren, T. Wang, F.H. Chen, 2009. Pseudo-feathery dunes in the Kumtagh desert reclassified as linear dunes and zibars. Aeolian Research, 1(1-2); 87-89.

Wasson, R.J., K. Fitchett, B. Mackey, B., R. Hyde, 1988. Large-scale patterns of dune type, spacing and orientation in the Australian continental dunefield. Australian Geographer, 19(1); 89-104.

Wiggs, G., 2019. Desert dunes: Form and process. In: A. Warren, I. Livingstone, (eds.) Aeolian Geomorphology: A New Introduction. Wiley, Chichester, pp 133-155.

Xiao, J., X. Xie, H. Zhao, C. Chen, X. Ma, J. Qu, Z. Yao, 2021. Seasonal changes and migration of longitudinal dunes in the northeastern Rub'al Khali Desert. Aeolian Research, 51; p.100710.

Zhang, H., Z. Wu, J. Hu, Z. Zhang, B. Xiao, J. Ma, 2021. Numerical simulation of wind field and sand flux in crescentic sand dunes. Science Reports, 11(1); 1-18.

Zheng, Z., S. Du, H. Taubenböck, H., X. Zhang, 2022. Remote sensing techniques in the investigation of aeolian sand dunes: A review of recent advances. Remote Sensing of Environment, 271; p.112913.