

Depósitos eólicos

Onde desenvolvem-se depósitos eólicos?

- Disponibilidde de areia e silte ===>
- Cobertura vegetal mínima ===>
- Praias, desertos, planícies periglaciais, lagos secos.

Campos de dunas interiores



Arquitetura

Pré-
Vegetação

5.2 miles

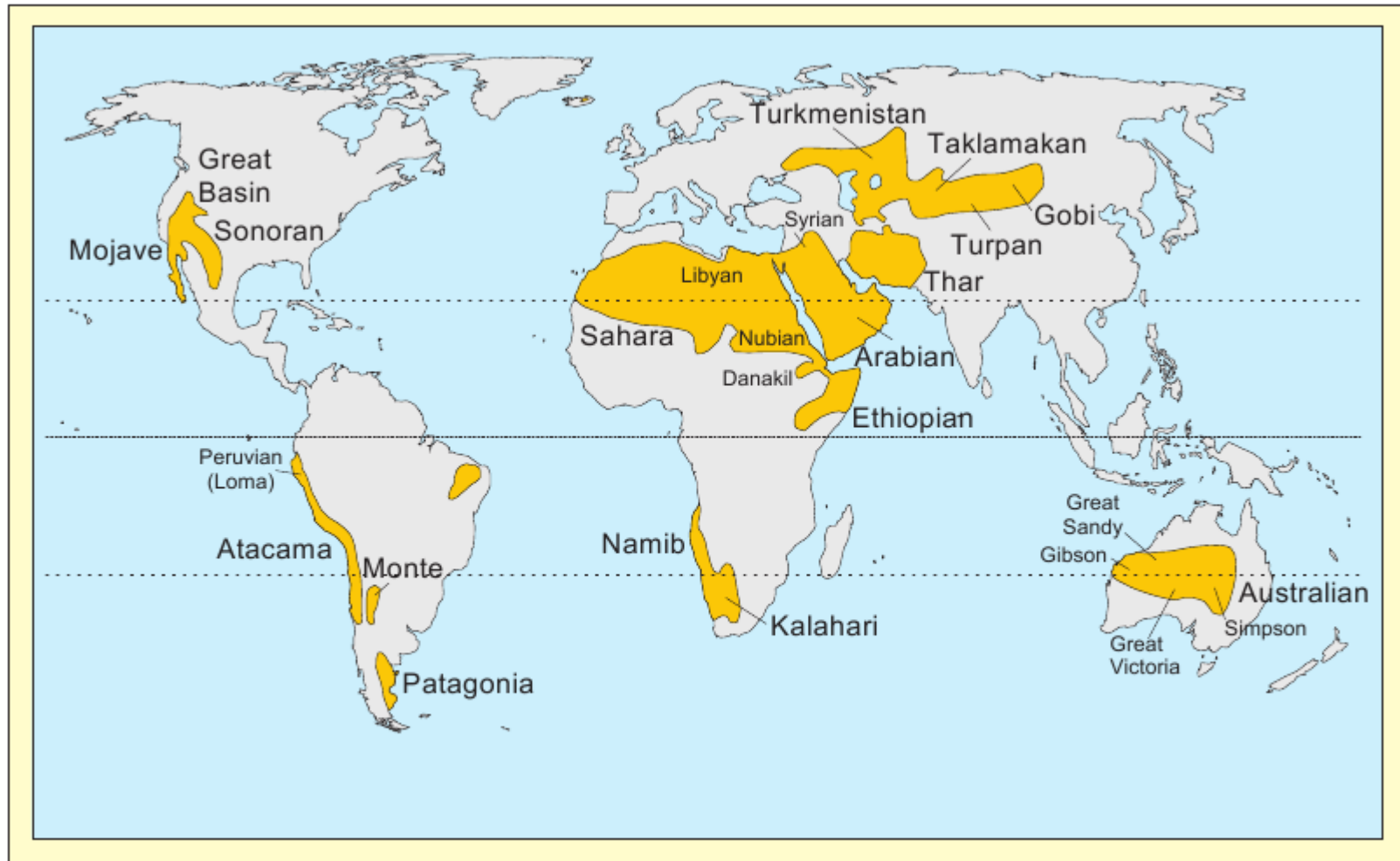


FIG. 1.—Distribution of the world's major climatic deserts.

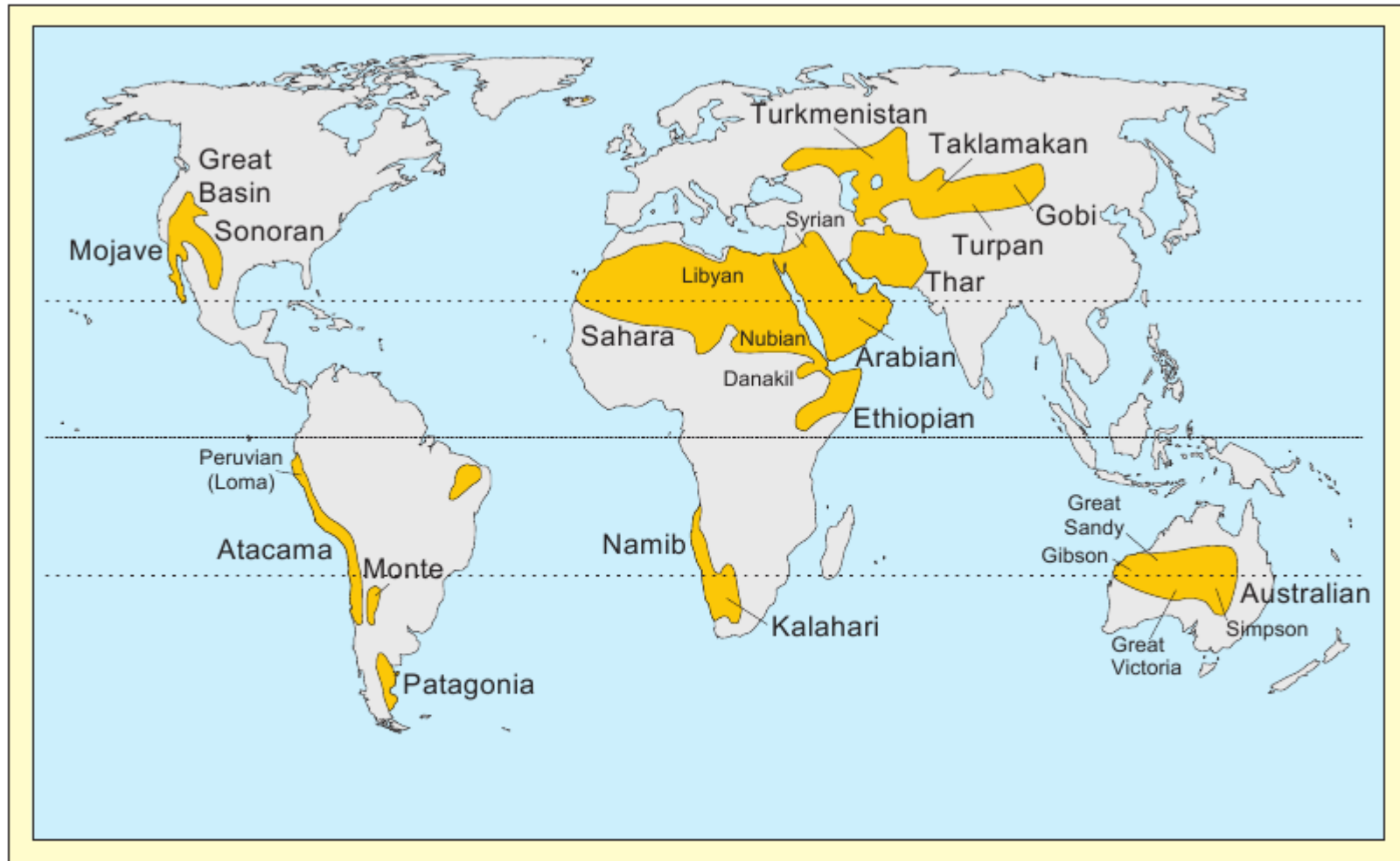


FIG. 1.—Distribution of the world's major climatic deserts.

Planaltos de baixa latitude, áreas próximas a correntes oceânicas frias, sobras de chuva.

Mudanças climáticas

Campos de dunas de desertos atuais

Máximo glacial (18ka)

Trilhas de loess and poeira de aerosol no máximo glacial

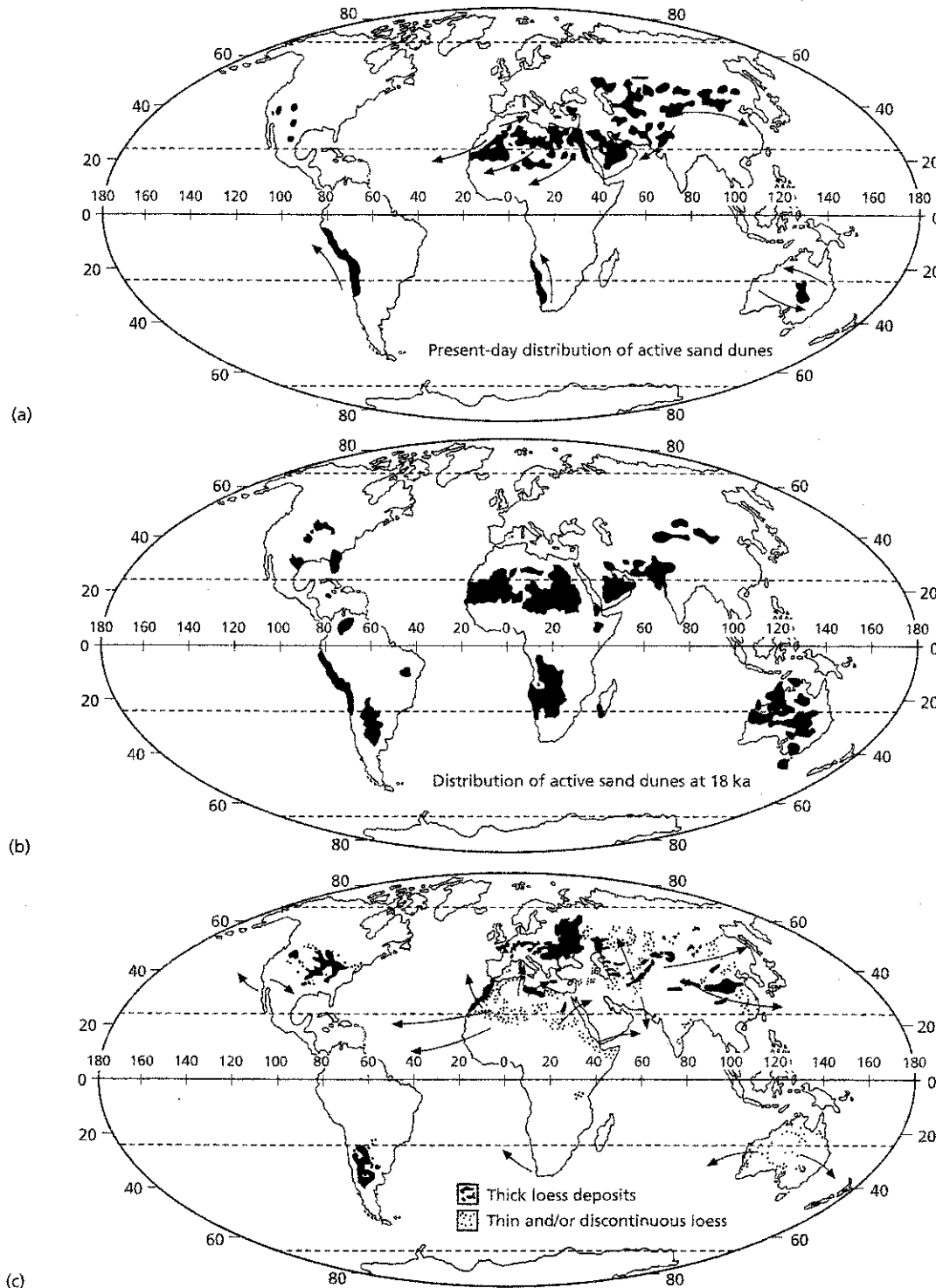
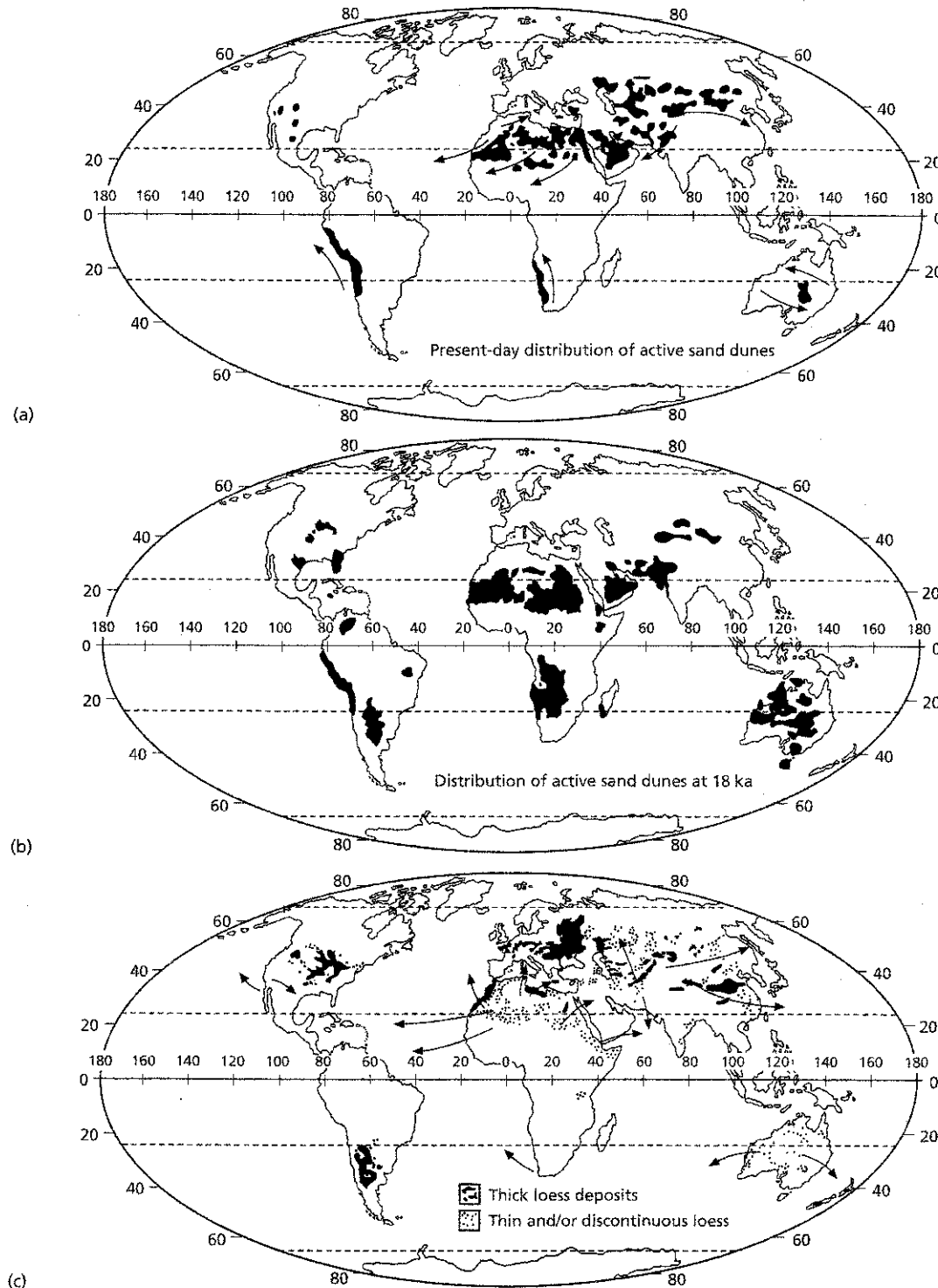


Fig. 16.2 Distribution of: (a) present-day active sand dunes
 distribution of mostly glacial-maximum loess and the mean
 trajectories of modern aerosol dust tracks. (Mostly after
 Williams *et al.*, 1993, and sources cited therein.)

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 Williams *et al.*, 1993, and sources cited therein.)



(c)

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Máximo glacial =
 maiores campos de
 dunas!

Aridez e energia dos
 ventos aumentadas.



White S

White Sands (NM, EUA)

Image © 2009 DigitalGlobe
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32°50'52.49" N 106°23'57.69" O

elev 1189 m

Altitude do ponto de visão 43.76 km





White Sands (NM, EUA)

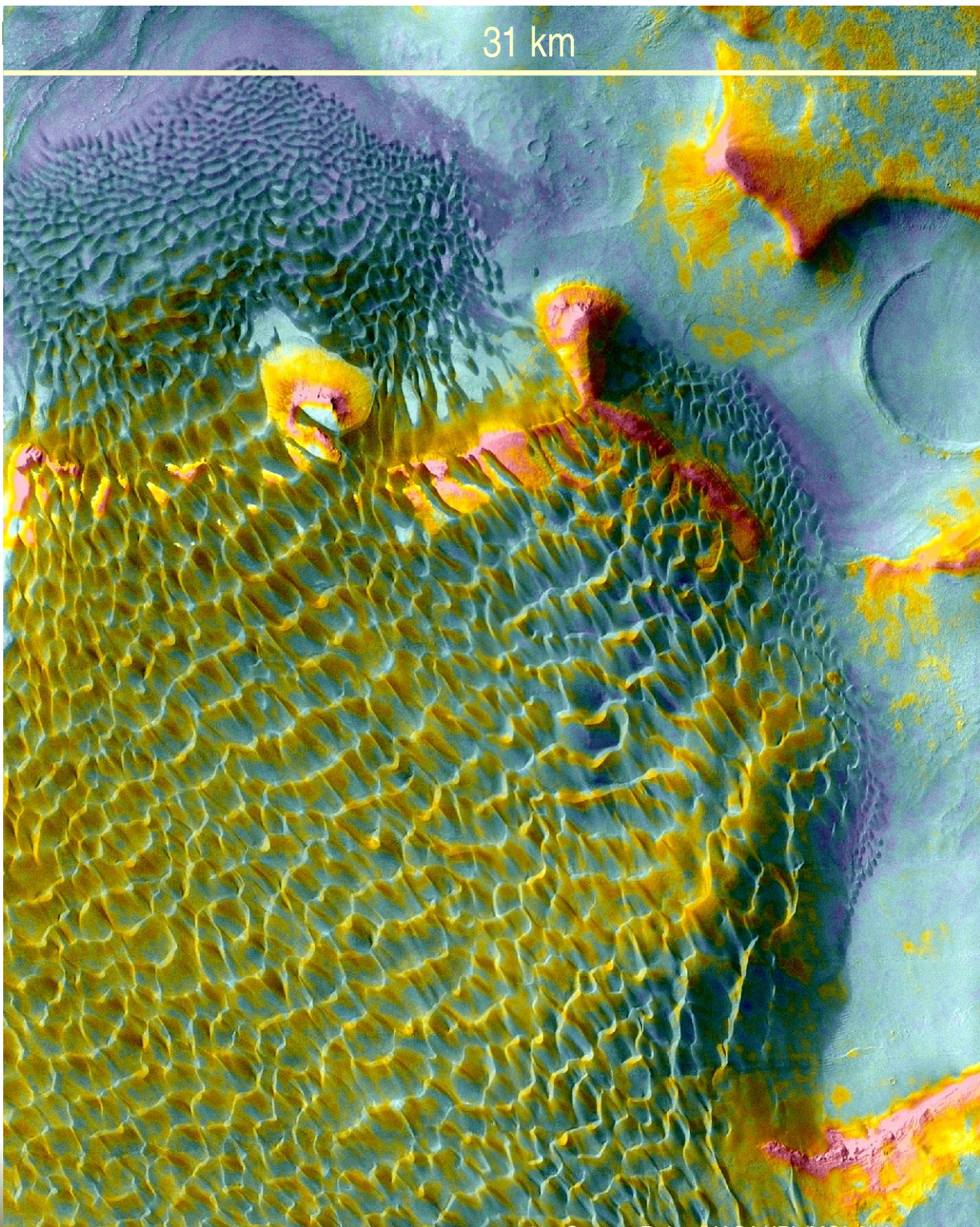
© 2008 Google

Image © 2009 DigitalGlobe
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elev 1219 m

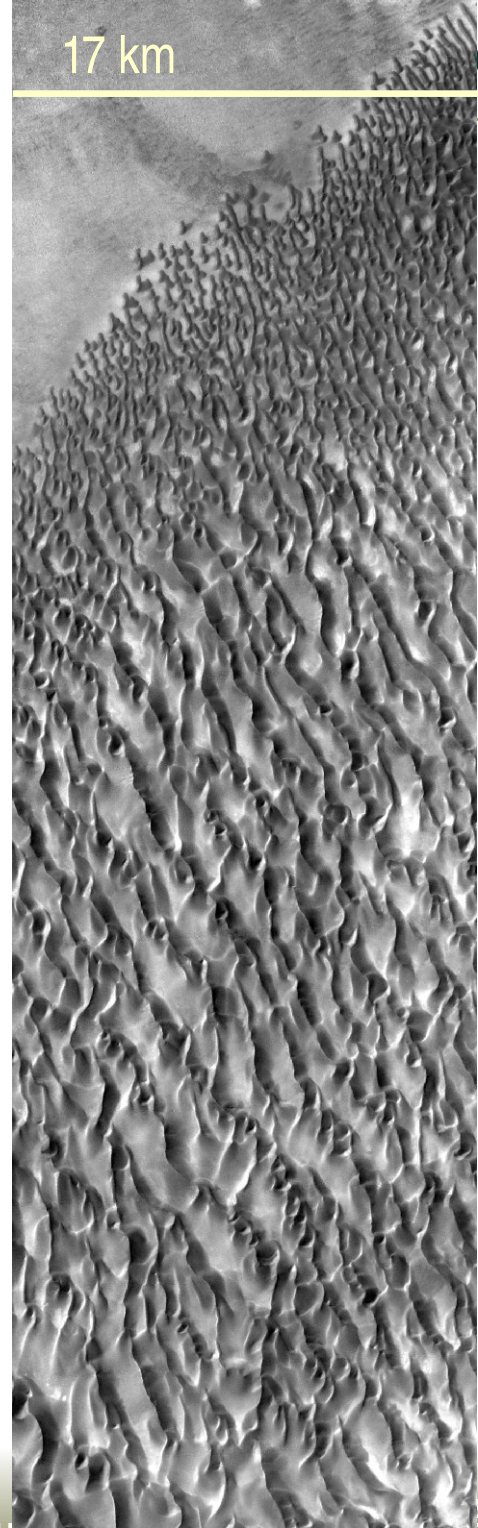
10 Nov 2006 Altitude do ponto de visão 10.00 km





31 km

Cratera Rabe (NASA/JPL/MOLA)



17 km

Cratera Proctor (NASA/JPL/MOLA)

CIAS

USP

Arquitetura

Vegetação

Campos de dunas costeiras



Arquitetura

Pré-
Vegetação



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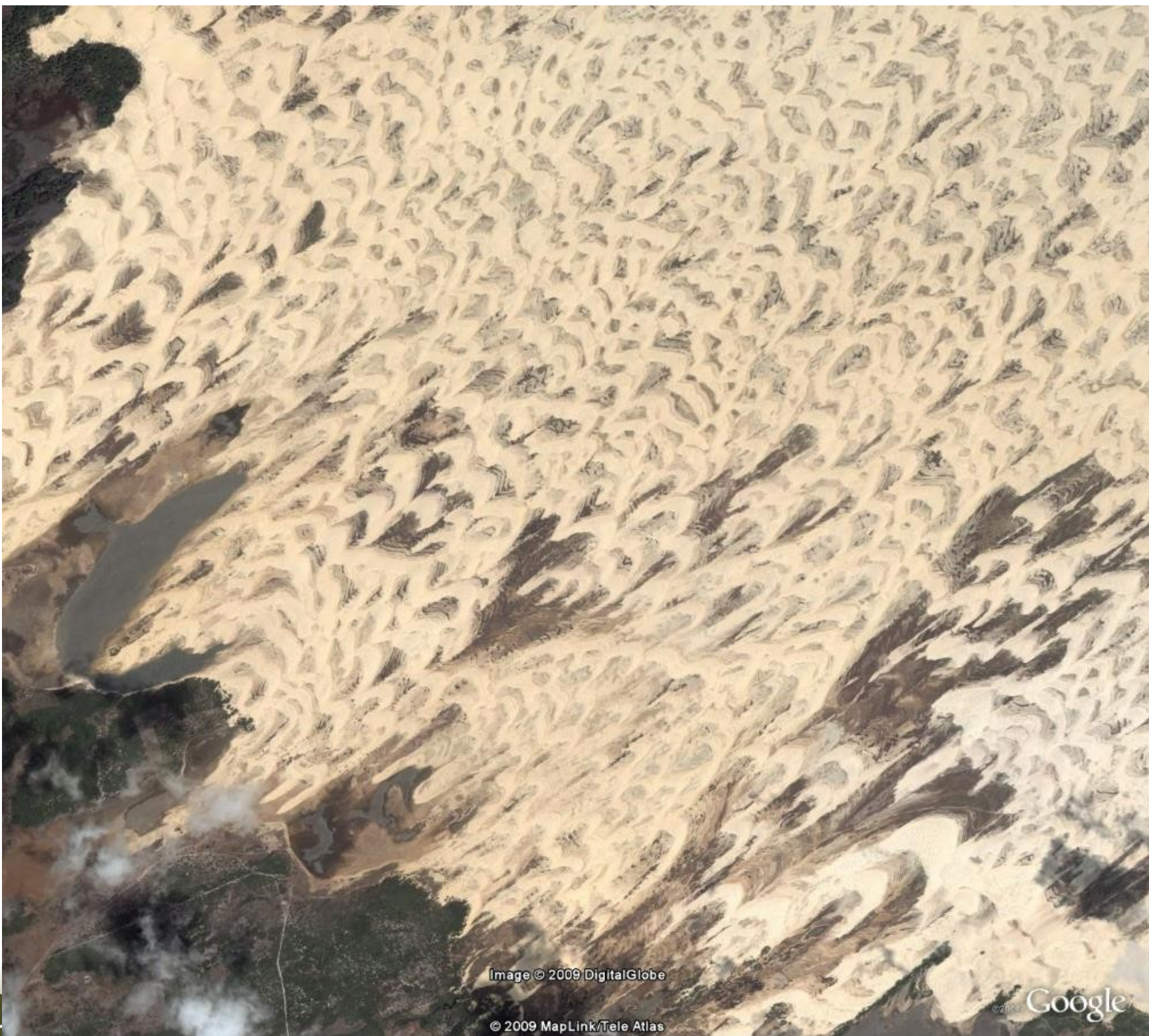


Image © 2009 DigitalGlobe

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elev 3 m

Google

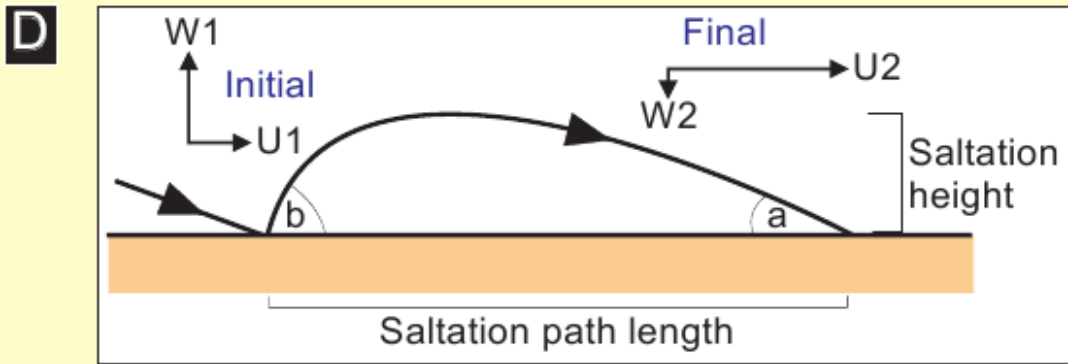
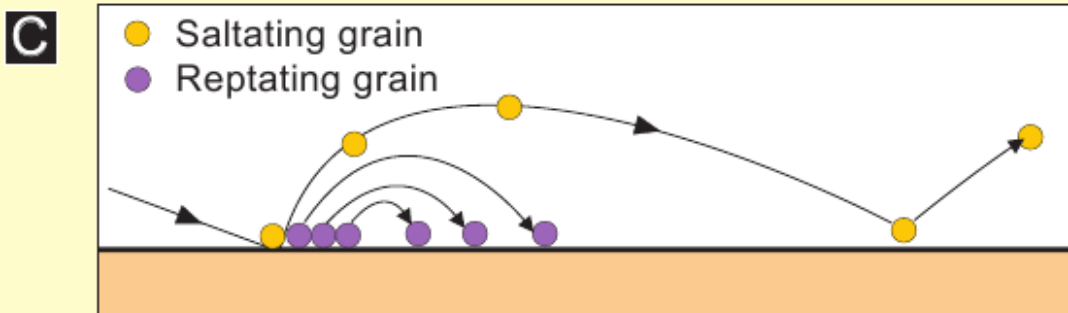
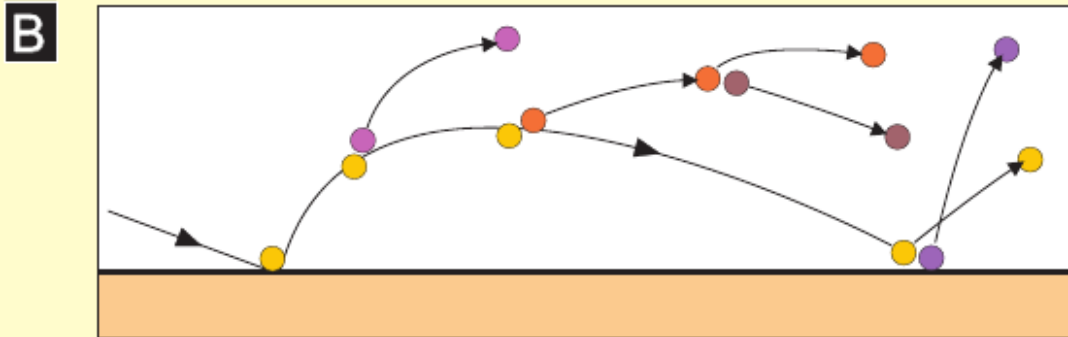
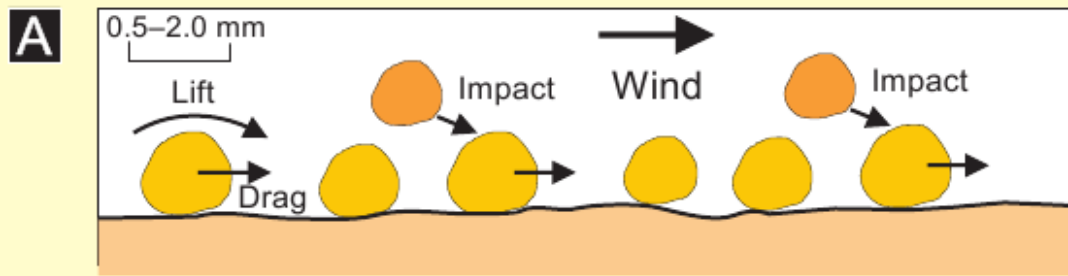


Elementos morfológicos

- Campo de dunas (*erg – sand seas*)
 - Marcas onduladas eólicas ($H \leq 0.1$ m; $\lambda = 0.02$ a 2.0 m) $\lambda/H = 25$ a $40+$
 - Dunas
 - Draas
 - Interdunas

- Lançóis de areia

- Pavimentos de deflação



Methods of eolian grain transport. A) Surface creep. B) In-air collisions of saltating grains maintains momentum, keeping grains aloft. Ground impacts induce new grains to saltate. C) Impact of saltating grains with grains on bed drives reptation. D) The ballistic trajectory of a saltating sand grain. W and U represent vertical and horizontal velocities, respectively. a is the approach angle, b is the take-off angle.

Moutney (2006)

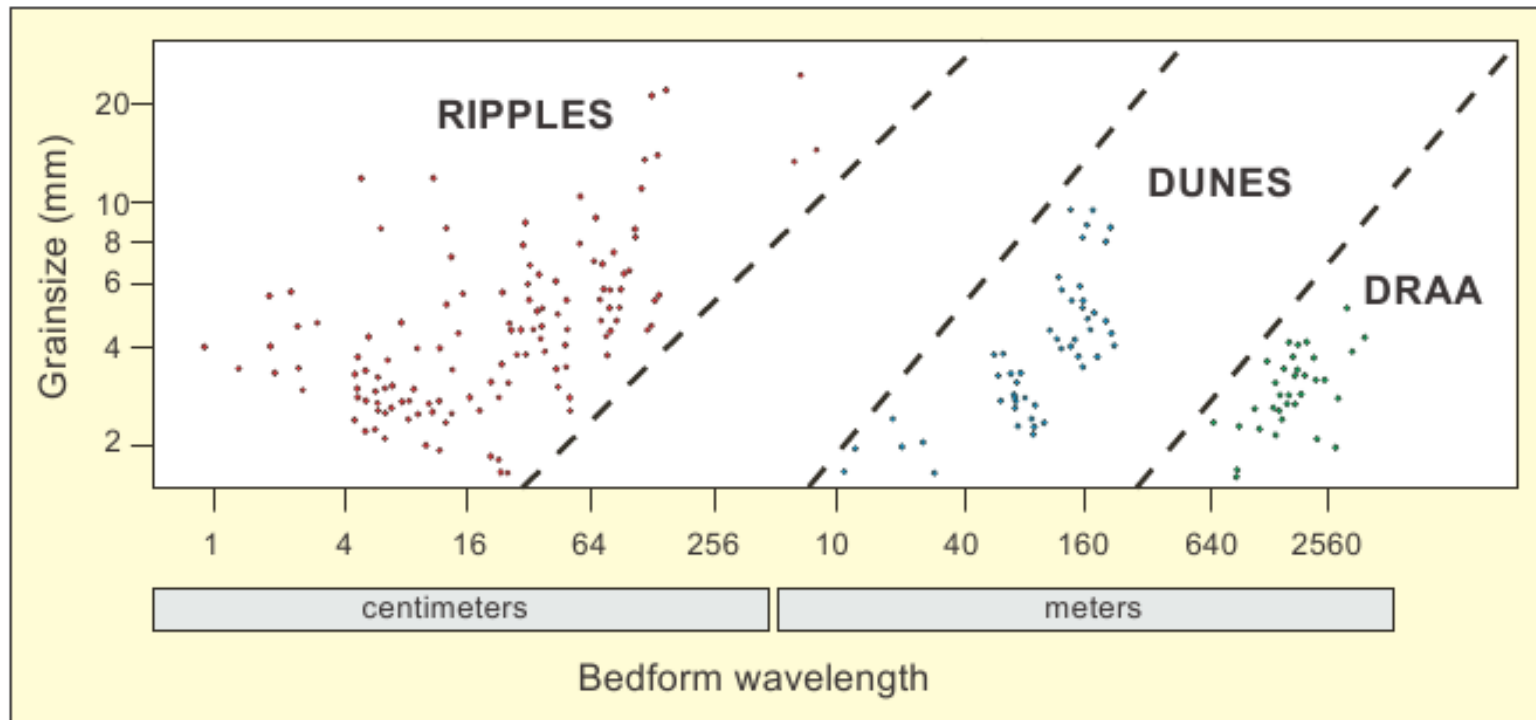


FIG. 7.—Grain size (coarsest twentieth percentile) versus wavelength for eolian bedforms. Note the three distinct groups representing ripples, dunes, and draa. Modified after Wilson (1972).

Mountney (2006)



Ondulações



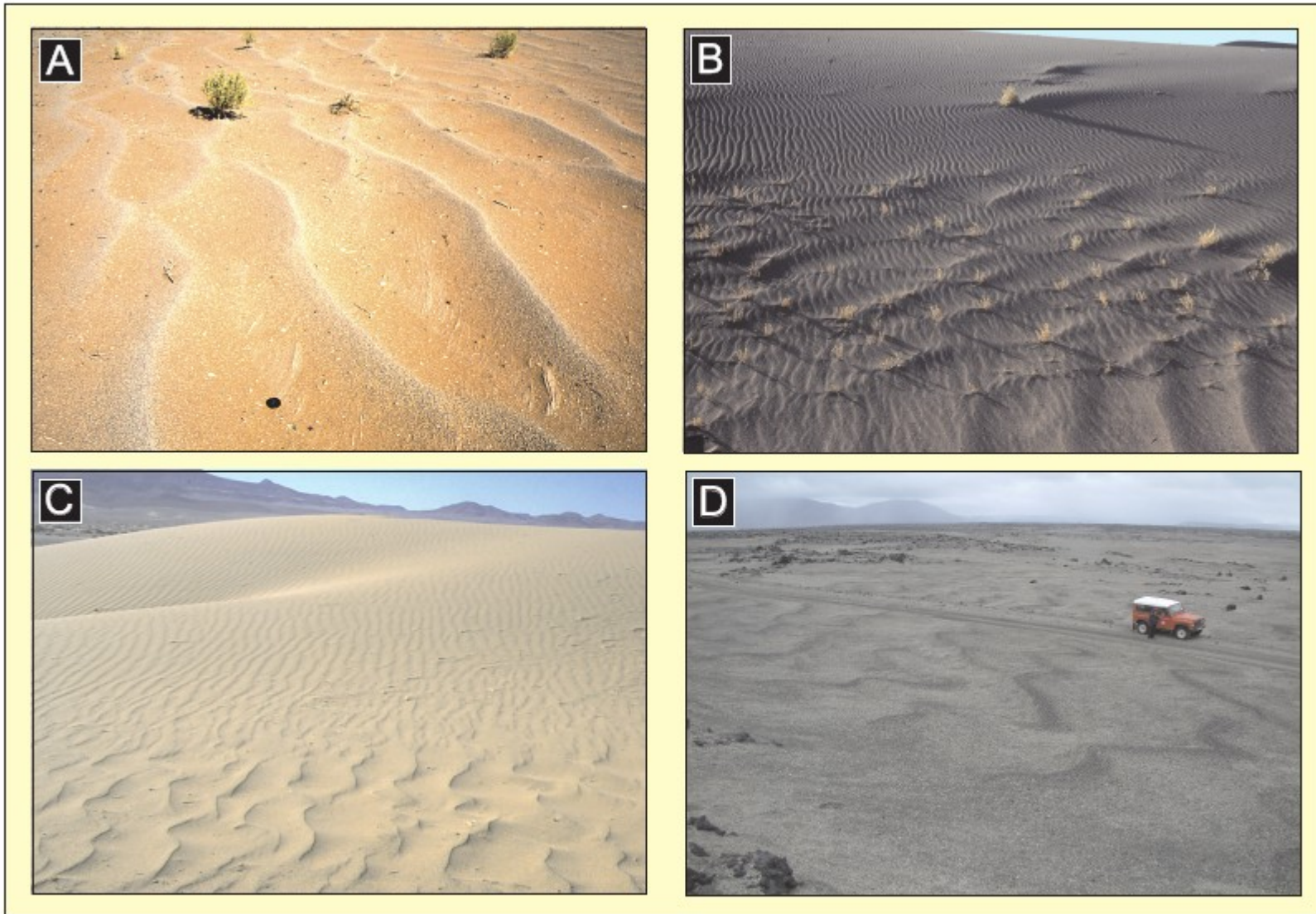
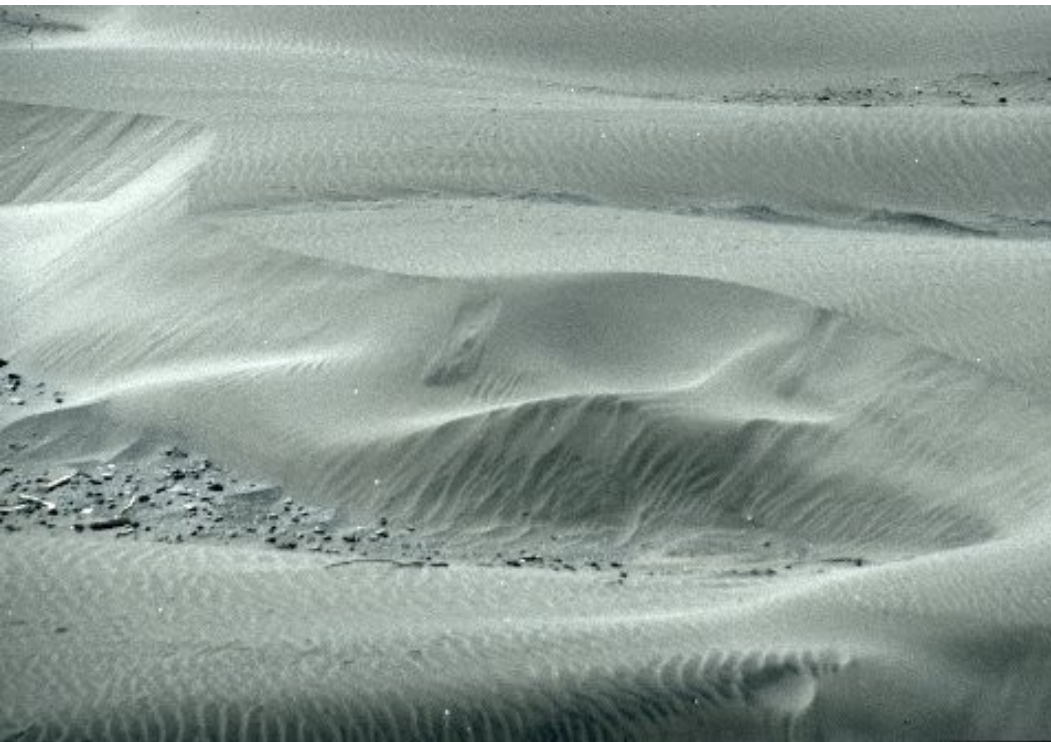


FIG. 8.—Examples of eolian ripple forms. **A)** Sinuous crested with coarser grains on crests. Skeleton Coast, Namibia. **B)** Two scales of superimposed ripples. Idaho (courtesy of John Collinson). **C)** Two scales of ripples developed on the stoss slope of an eolian dune. Huab Basin, Namibia. **D)** Sinuous-crested eolian granule megaripples. Askja sandsheet, central Iceland.

Mountney (2006)

Draa

Duna

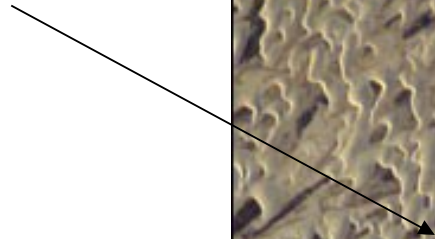




Lençol de areia



Campo de dunas
(dunas e depressões
interdunares)

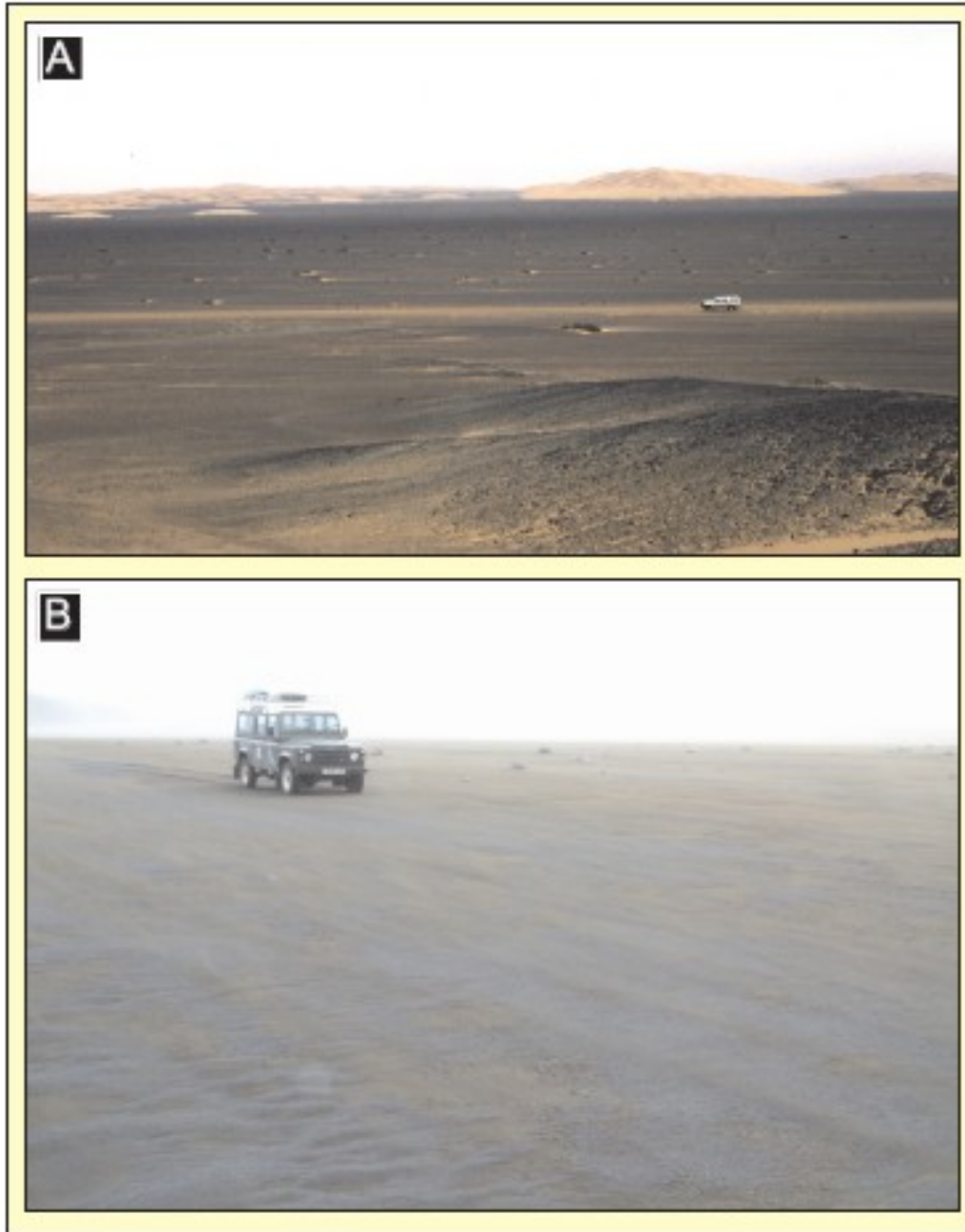


Zona de deflação



Lençol de areia





Morphology of modern sand sheets. A) Skeleton Coast, northern Namibia. Note dune field in far distance. B) Askja, central Iceland.

Mountney (2006)

Zonas de deflação



Depressão interdunar



Classificação de dunas

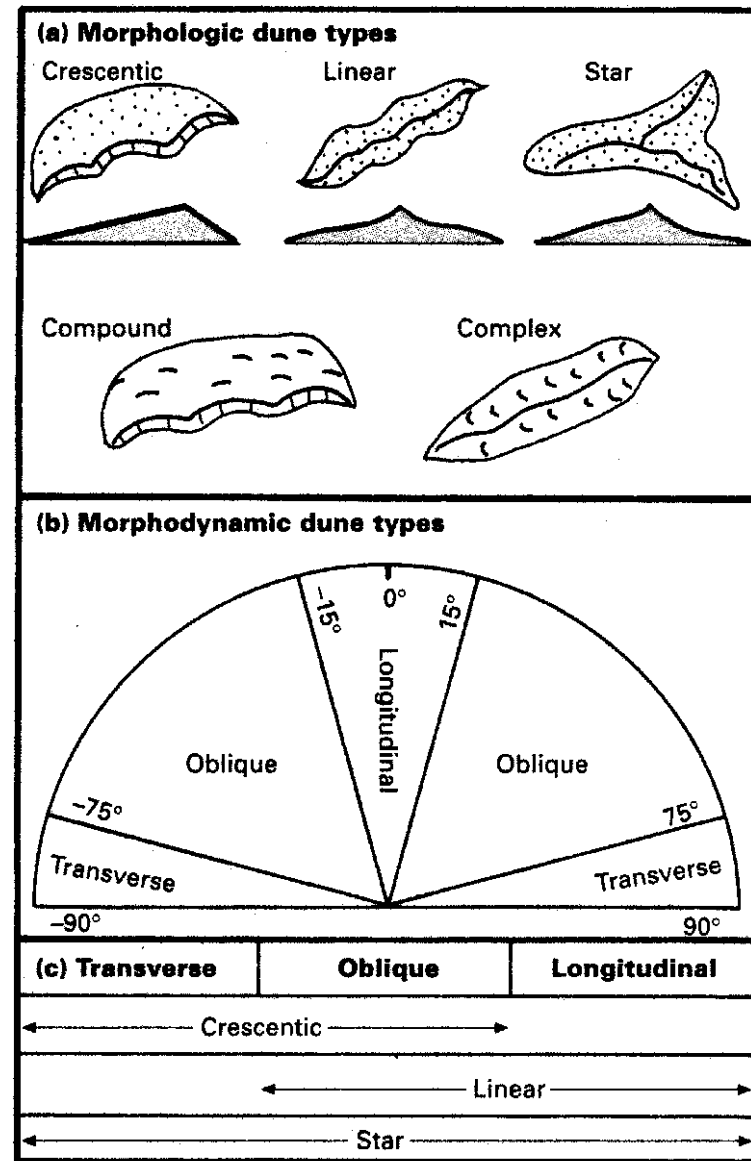
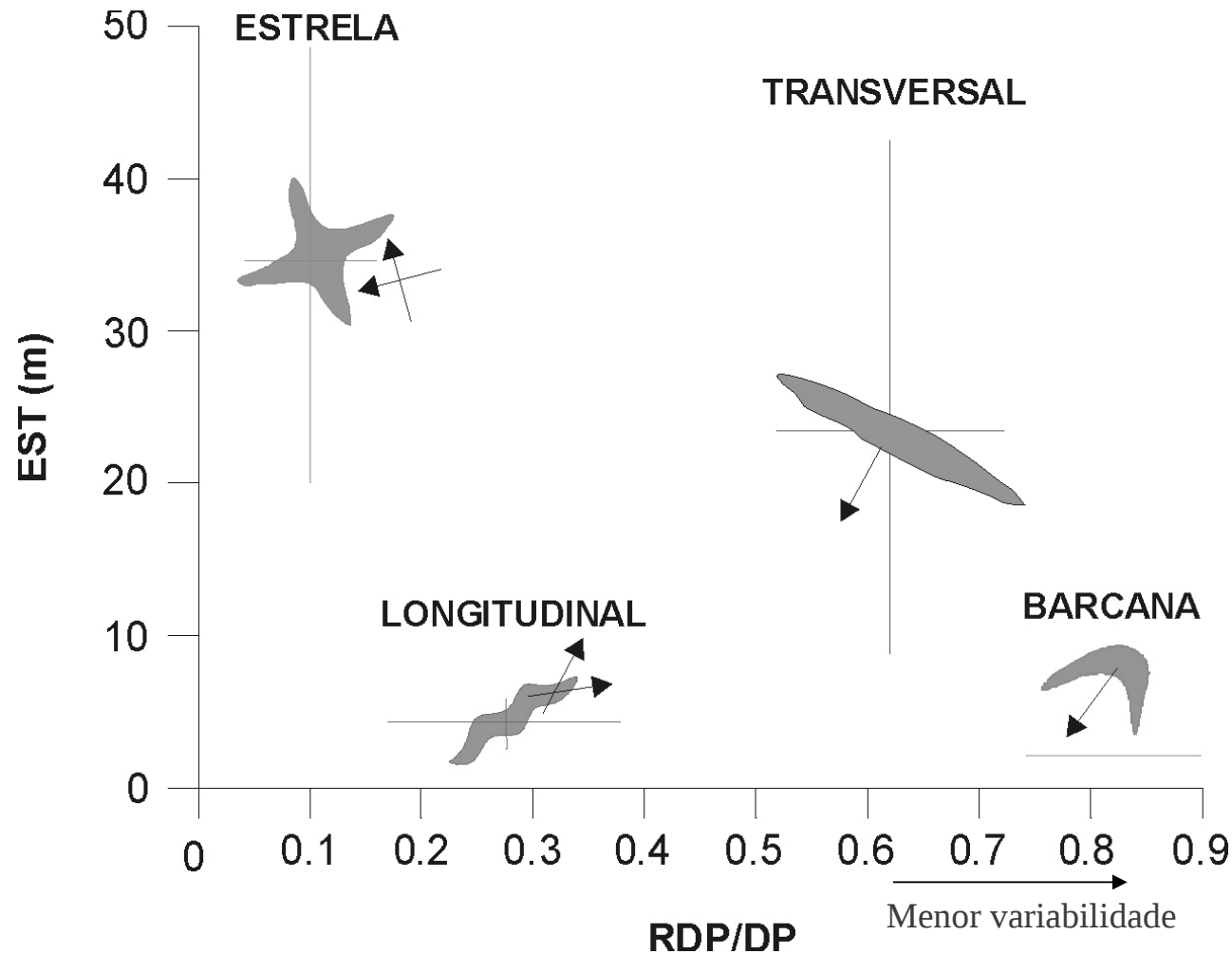


Figure 5.19 Classification of dunes. (a) Morphological dune types shown in plan view and cross-section for simple dunes, and plan view for compound and complex dunes. (b) Morphodynamic dune types based on orientation of crestline relative to resultant transport direction. (c) Probable range of morphological and morphodynamic dune types (modified from Hunter, Richmond & Alpha, 1983; Kocurek, 1991).

Dunas livres



RDP/DP = variabilidade do regime de ventos

EST = disponibilidade de areia

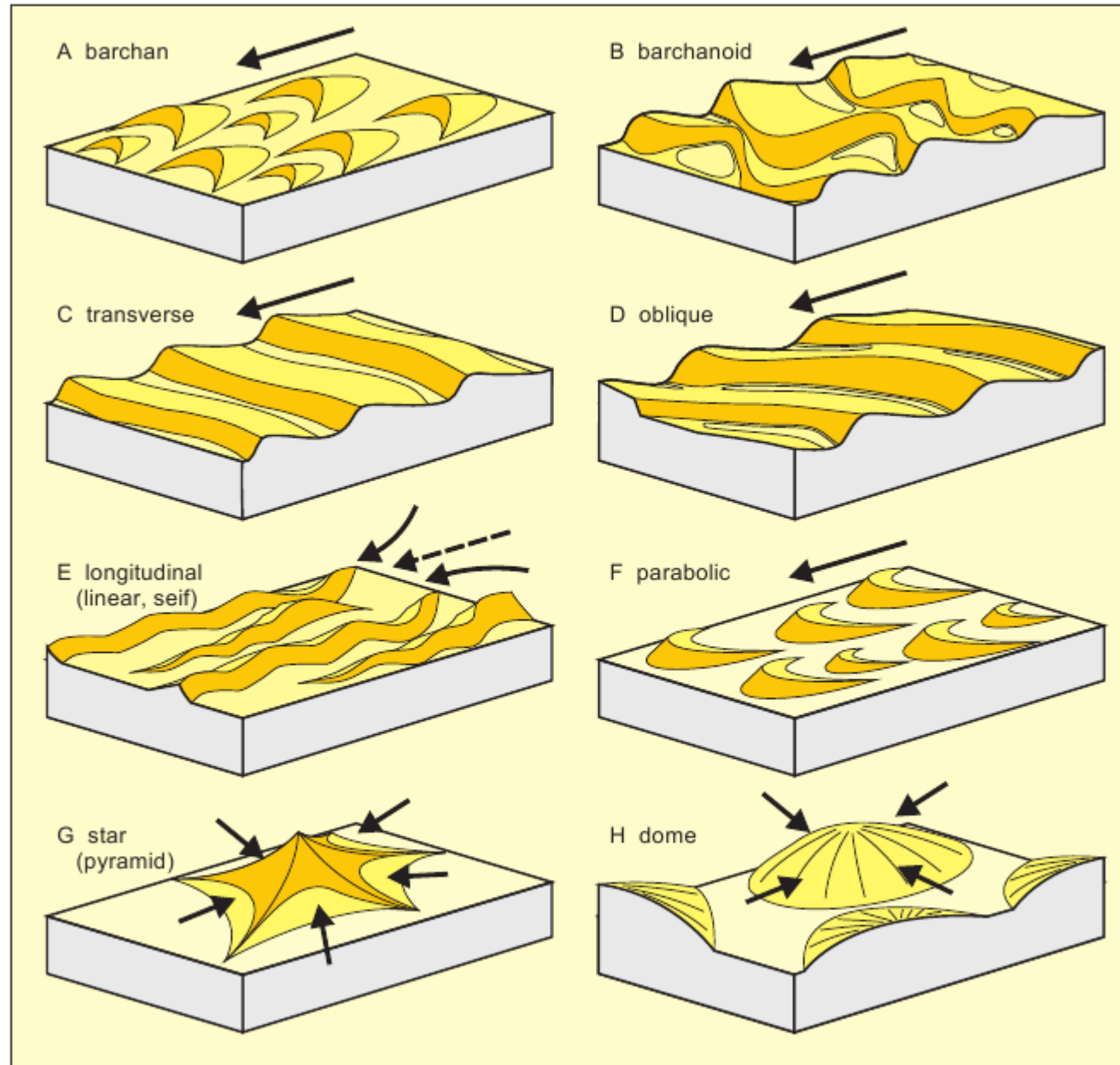


FIG. 10.—Three-dimensional forms of some common dune types. The arrows mark the dominant directions of the effective winds and in case E, the dotted arrow indicates the resultant effective direction.

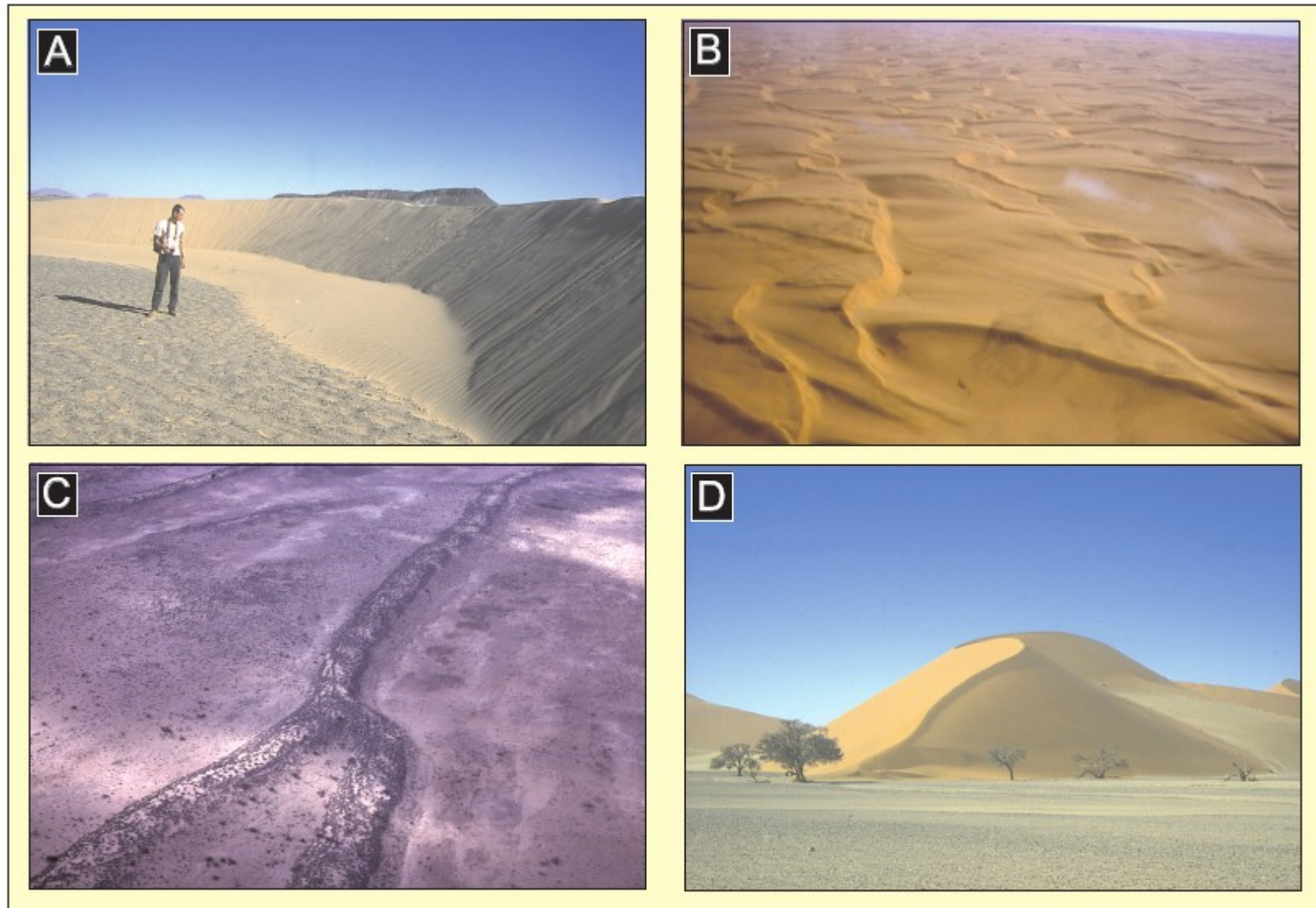


FIG. 11.—Examples of eolian dune forms. **A)** Slipface and plinth of crescentic barchan dune. Skeleton Coast, Namibia. **B)** Transverse dunes. Western Namib Sand Sea. **C)** Linear dune ridge partly stabilized by vegetation. Lake Eyre Basin, Australia (courtesy of John Collinson). **D)** Large star dune, central Namib Sand Sea.

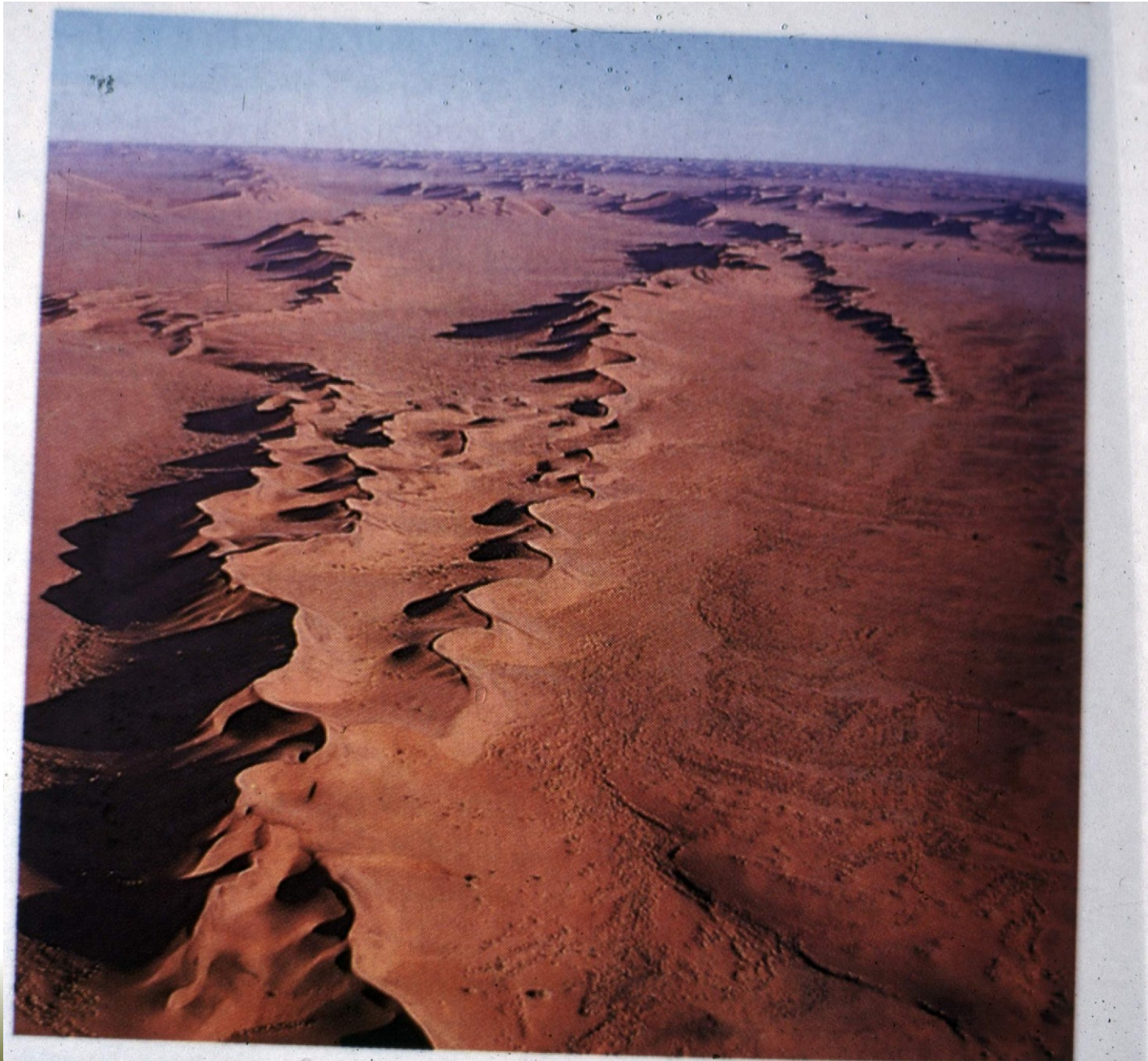
Dunas barcanas (*crescentic*) e cadeias barcanóides



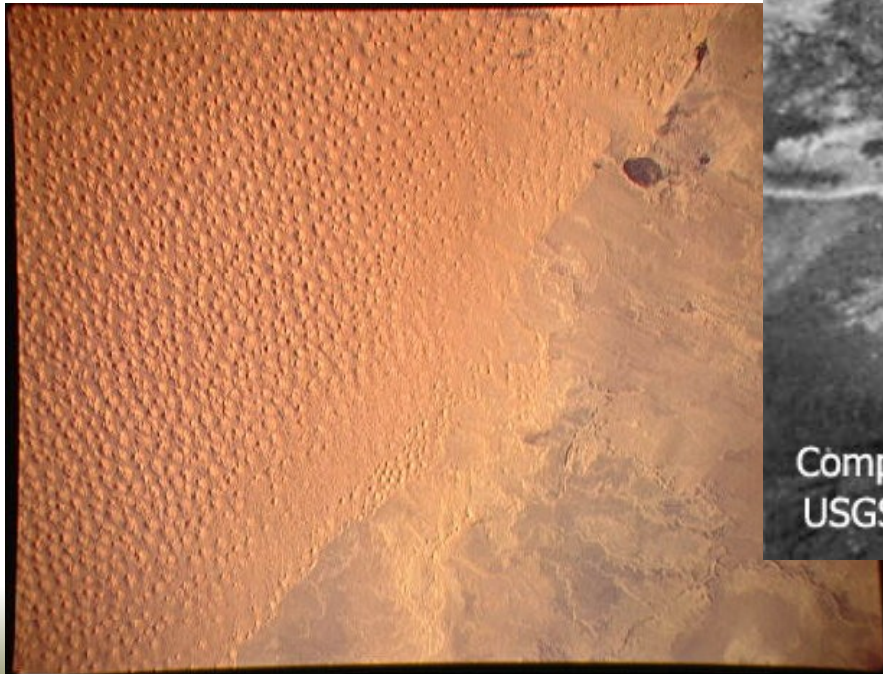
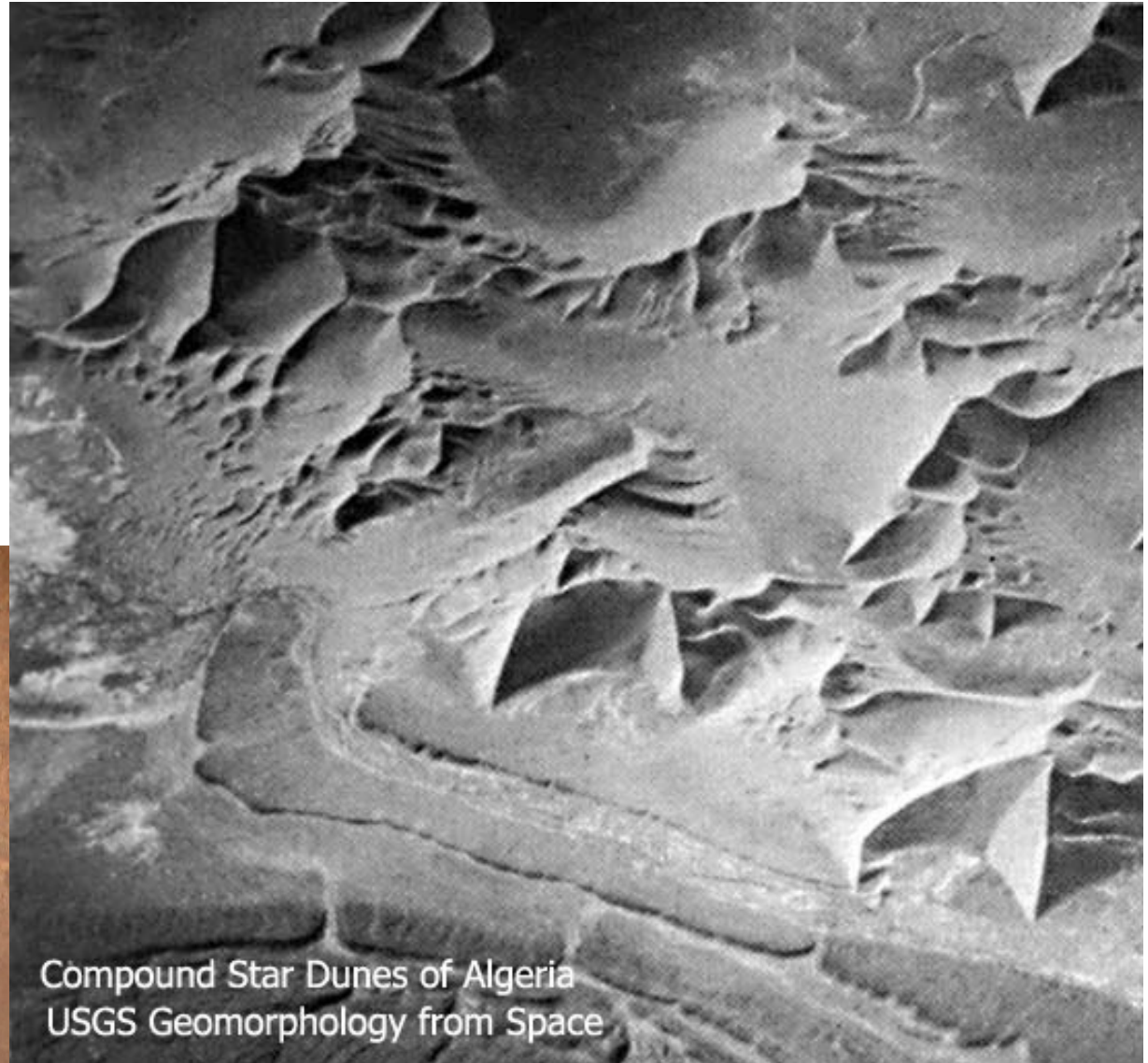
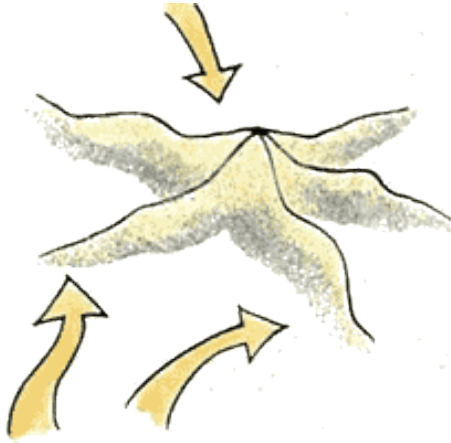
Dunas transversais



Dunas longitudinais (*seif*)



Duna estrela



Fácies

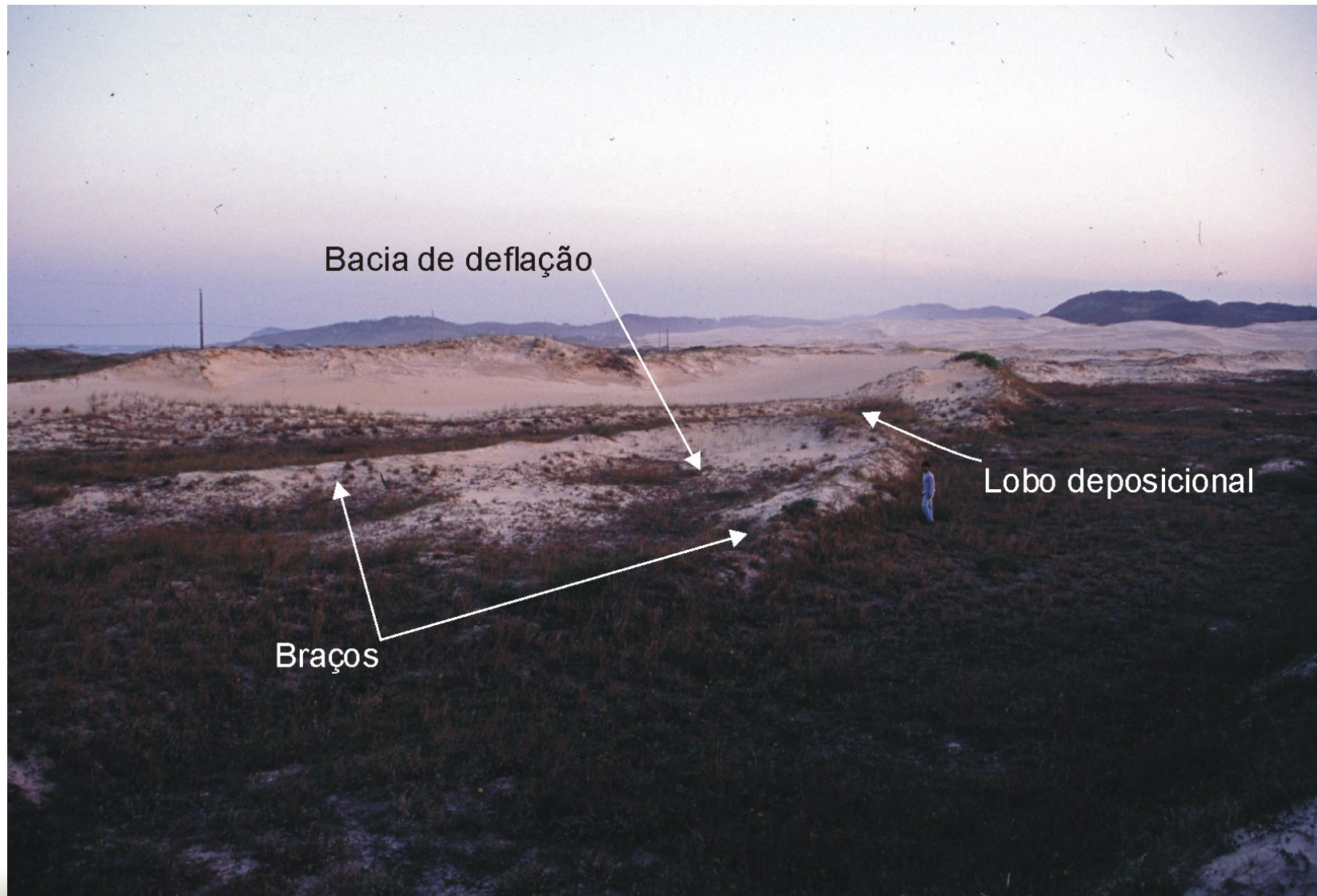
Arquitetura

Pré-
Vegetação

Leito

Dunas vegetadas

Duna parabólica



Duna frontal



Lobos de deflação (blowout)



Dunas livres = aporte sedimentar eólico elevado
Dunas vegetadas = aporte sedimentar eólico reduzido



Vento (aporte sedimentar)



Fácies sedimentares

Estratificação eólica:

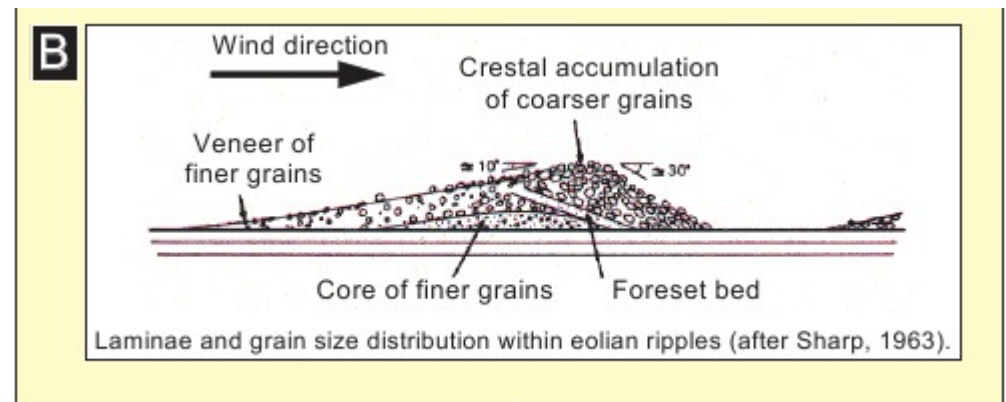
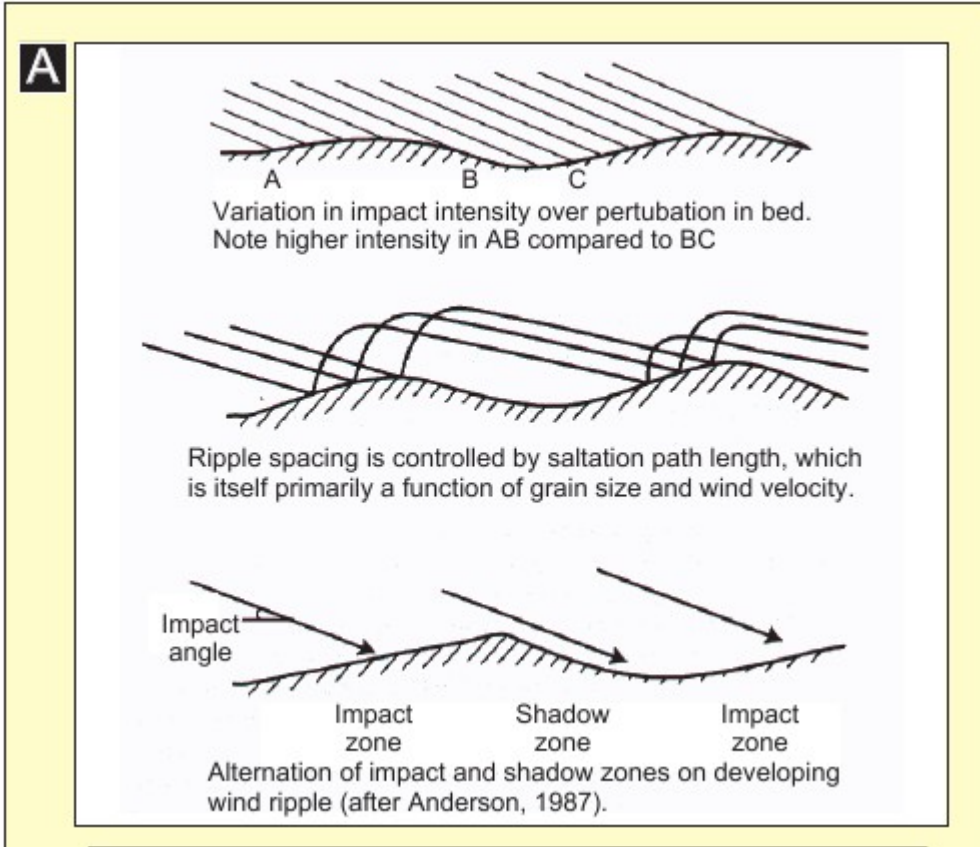
- Chuva de grãos (grain fall)
- Fluxo de grãos (grain flow)
- Laminação por migração de marcas onduladas (cruzada e transladante)

- **Laminação cruzada por migração de marca ondulada**
- **Laminação transladante (*translatent lamination*)**

Migração e cavalgamento de marcas onduladas

Marcada por variação granulométrica da crista para o pé da m.o. (ressalta apenas os planos de cavalgamento em baixo ângulo)

Raramente há também cruzadas de estratos fontrais da m.o.



Grãos maiores estacionam na zona de impacto e sofrem arrasto para a crista até decolarem novamente.

Grãos menores ficam aprisionados na zona de sombra e não param na zona de impacto.

FIG. 9.—Generation of eolian ripples. **A)** Model for the generation of saltation ripples. After Anderson (1987). **B)** Grain texture in eolian ripples. After Sharp (1963).

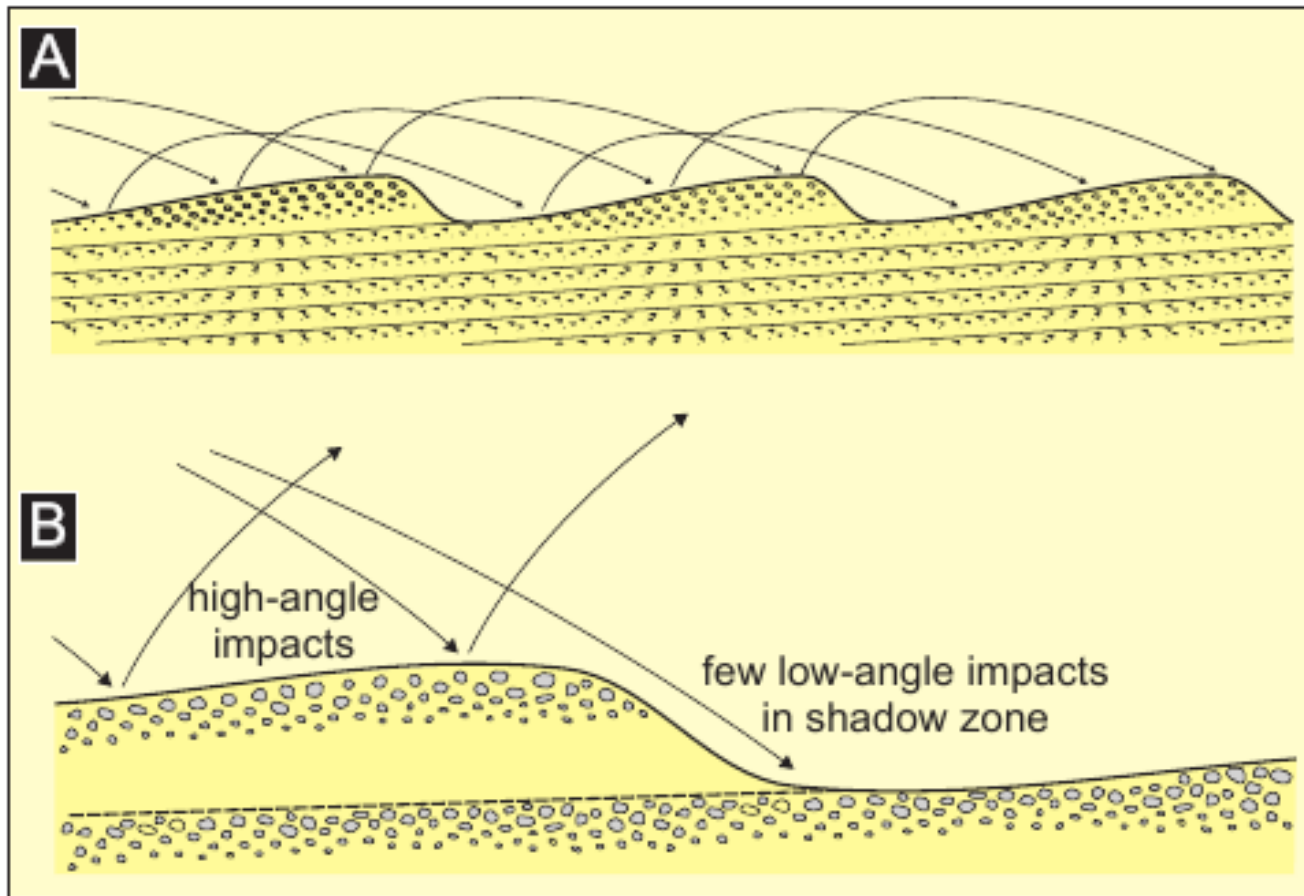
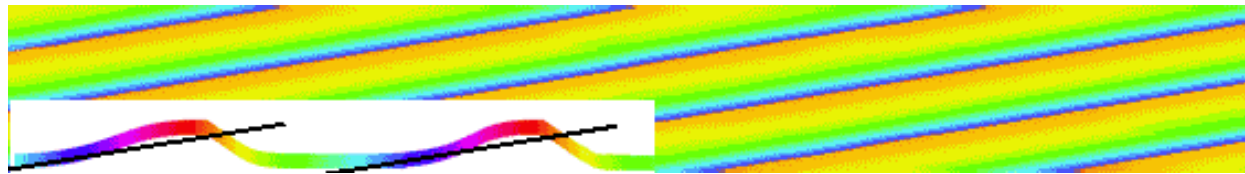


FIG. 17.—Wind ripples generated by ballistic impact of grains. The ripple spacing relates in a general way to the saltation path length, which is the characteristic distance that individual grains hop downwind as a result of grain collision on the bed. The saltation path length is a function of grain size, shape and density, and mean wind velocity and gustiness close to the bed. **A)** The migration of wind ripples generates subparallel lamination. **B)** The impact angle of saltating sand grains differs between stoss sides and lee slopes. High-angle impacts on the stoss of the bedforms promotes creep of coarser grains towards the ripple crest. Downwind-facing lee slopes form a shadow zone where relatively few low-angle impacts occur, thus encouraging the accumulation of finer grains in ripple troughs. As ripples migrate downwind, this sorting mechanism generates lamination with inverse grading.

Laminação transladante



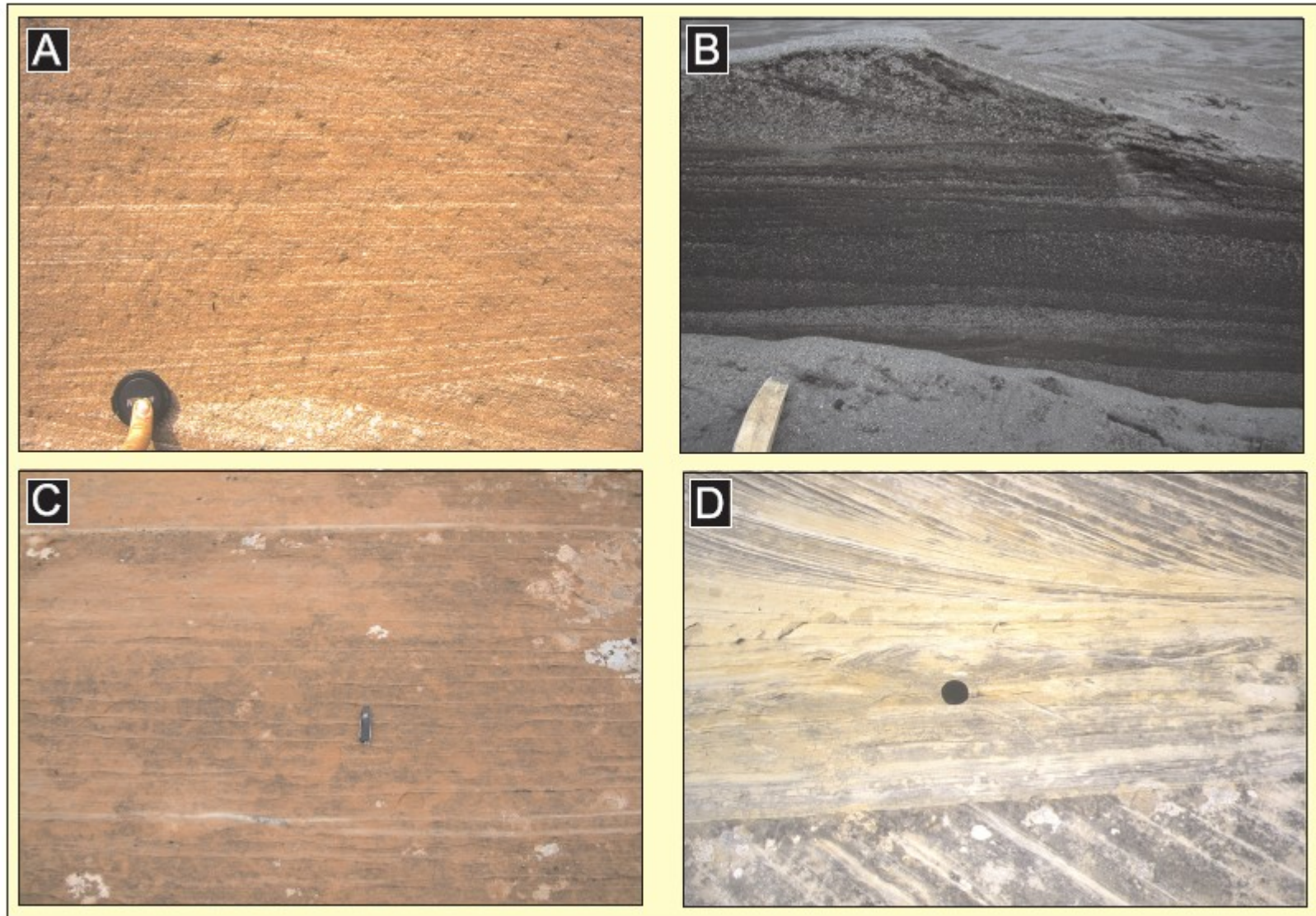


FIG. 15.—Examples of eolian ripple internal stratification. **A)** Pinstripe lamination, Etjo Formation, Cretaceous, Namibia. **B)** Inversely graded translantent strata, Askja, Iceland. **C)** Sharply defined wind ripple laminae interbedded with thin grainfall laminae. Lower Cutler Beds, Pennsylvanian–Permian, Utah, U.S.A. **D)** Wind-ripple strata on a dune plinth. Cedar Mesa Sandstone, Permian, Utah, U.S.A.

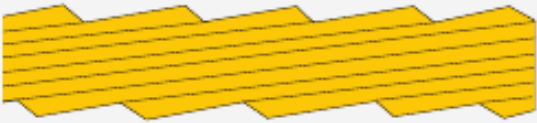
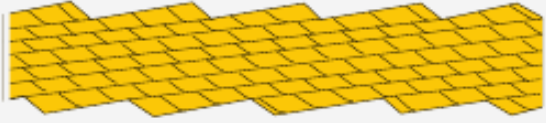
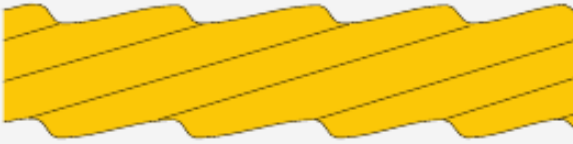
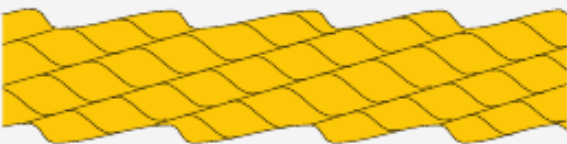

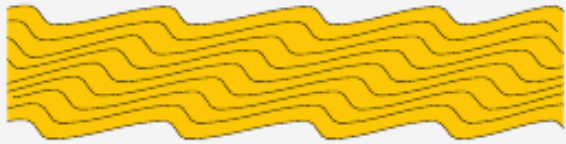
		Translatent strata	Rippleform laminae
Angle of ripple climb (α) relative to inclination of ripple stoss slope (β)	Subcritical ($\alpha < \beta$)	 <p>Subcritically climbing translatent strata</p>	 <p>Truncated ripple-foreset cross laminae</p>
	Critical ($\alpha = \beta$)	 <p>Critically climbing translatent strata</p>	<p>Incomplete rippleform laminae (ripple foreset cross-laminae)</p>  <p>Complete ripple-foreset cross laminae</p>
	Supercritical ($\alpha > \beta$)	 <p>Supercritically climbing translatent strata</p>	 <p>Complete rippleform laminae</p>

FIG. 16.—Classification of wind-ripple stratification types according to angle of ripple climb relative to the inclination of the stoss slope of the bedform and the presence or absence of cross-lamination. Modified after Hunter (1977).

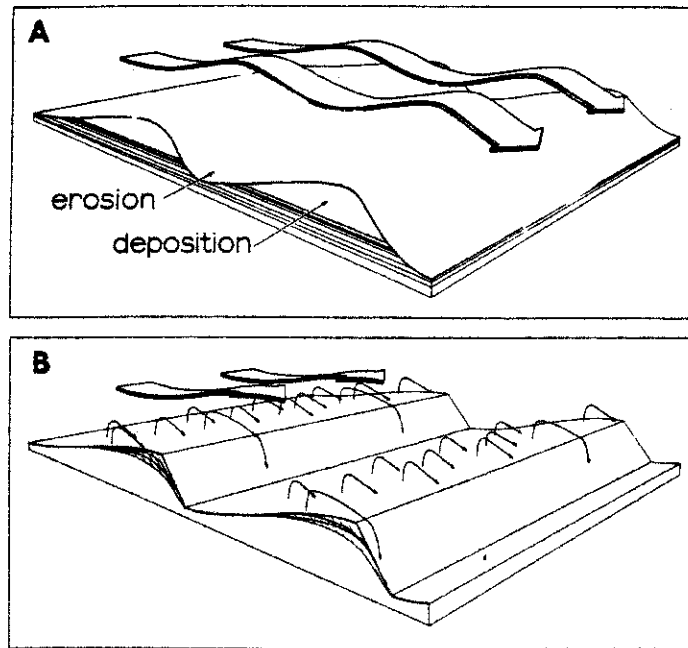


Figure 16.10 The hypothetical first two stages of transverse dune formation: A. wavelike pattern in the wind erodes and deposits alternate ridges and hollows; B. slipfaces develop.
 Source: Warren, 1979, figure 10.10, p. 337.

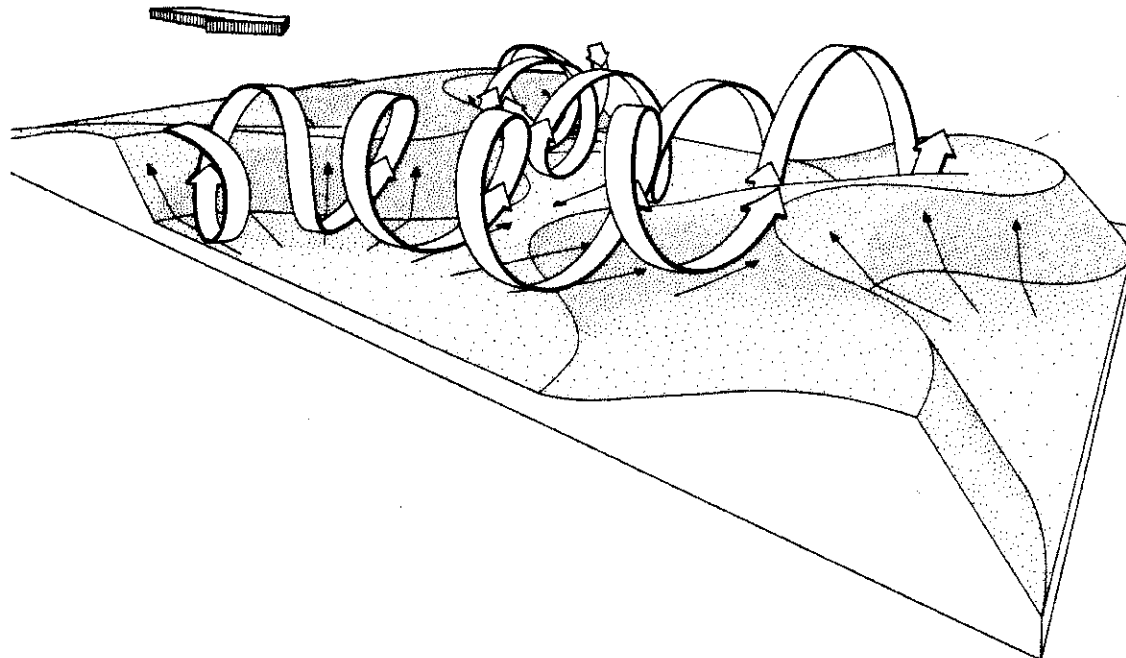


Figure 16.11 Horizontal vortex eddies associated with a barchanoid transverse dune which propagate downwind distortions in the subsequent ridge.
 Source: Warren, 1979, figure 10.12, p. 340.

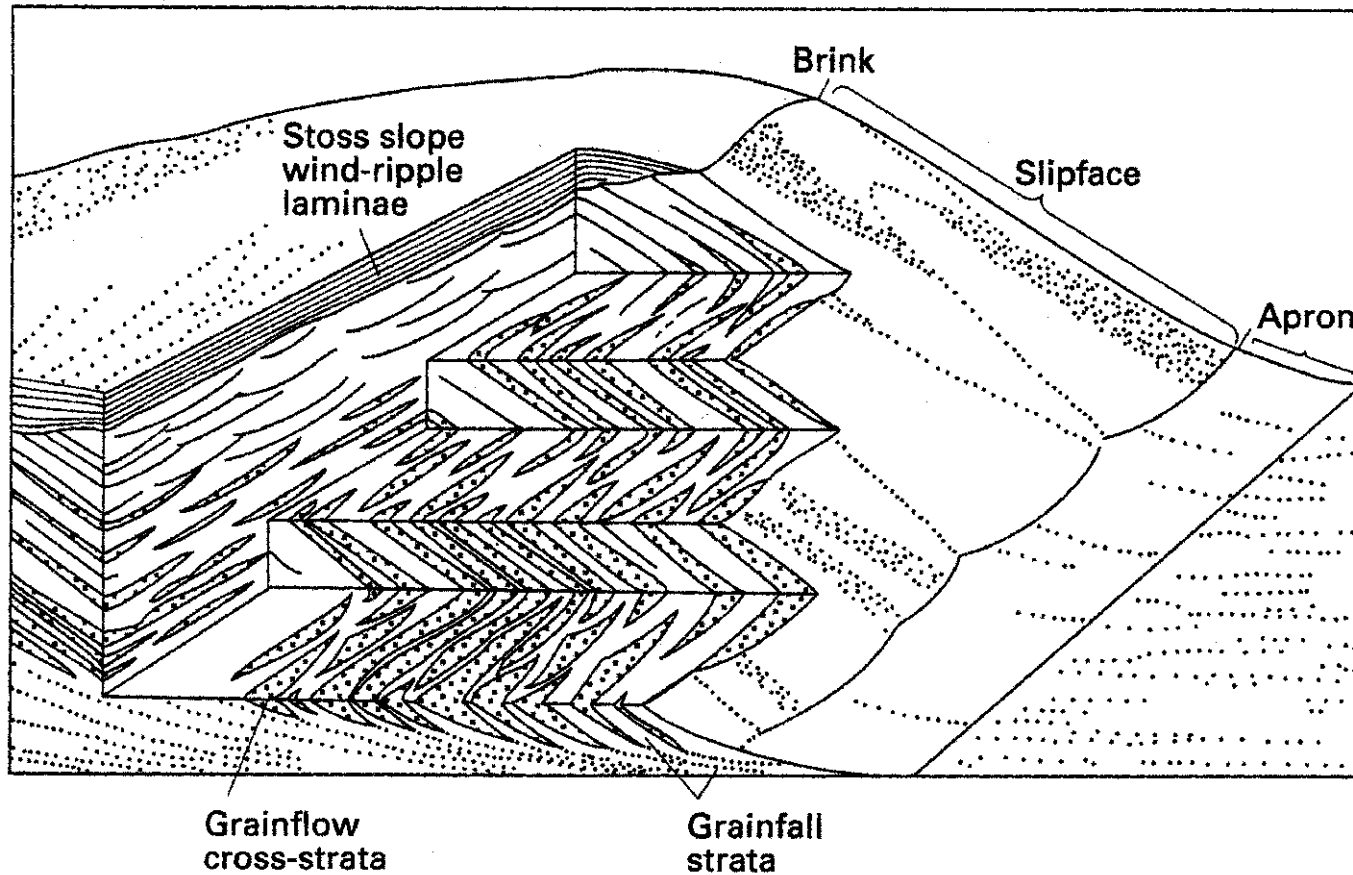


Figure 5.3 'Small' transverse dune, with slipface and basal apron, showing horizontal and cross-sections with stratification (from Hunter, 1977a).

Fluxo de grãos

Lentes mais espessas no pé da duna

Empacotamento aberto

Gradação inversa

Espessura de centímetros

Fluxo de grãos



Mecanismo de sustentação: choque entre grãos (pressão dispersiva)

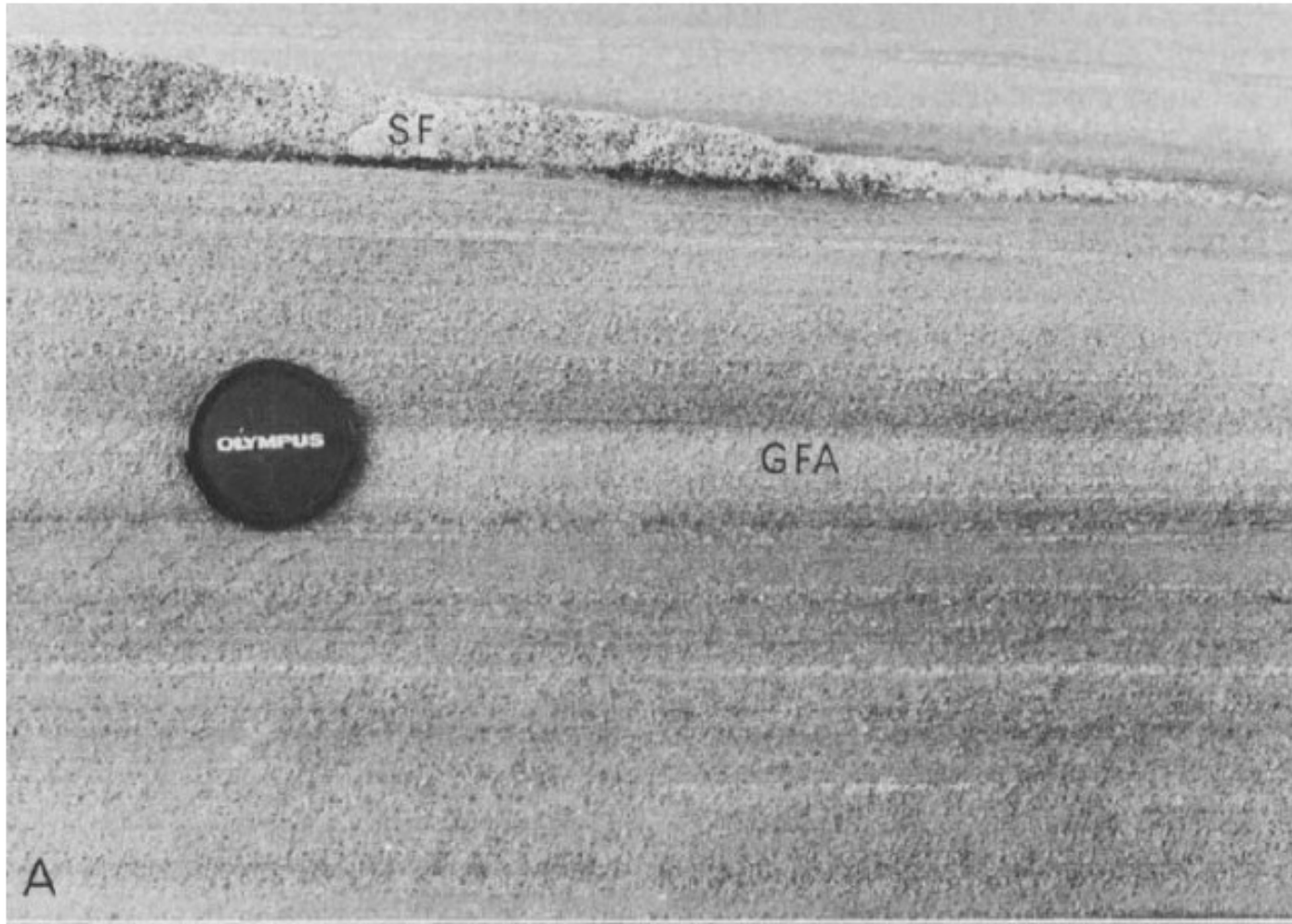
Introdução

Formas de Leito

Facies

Arquitetura

Pré-
Vegetação



Clemmensen & Abrhamsen (1983)



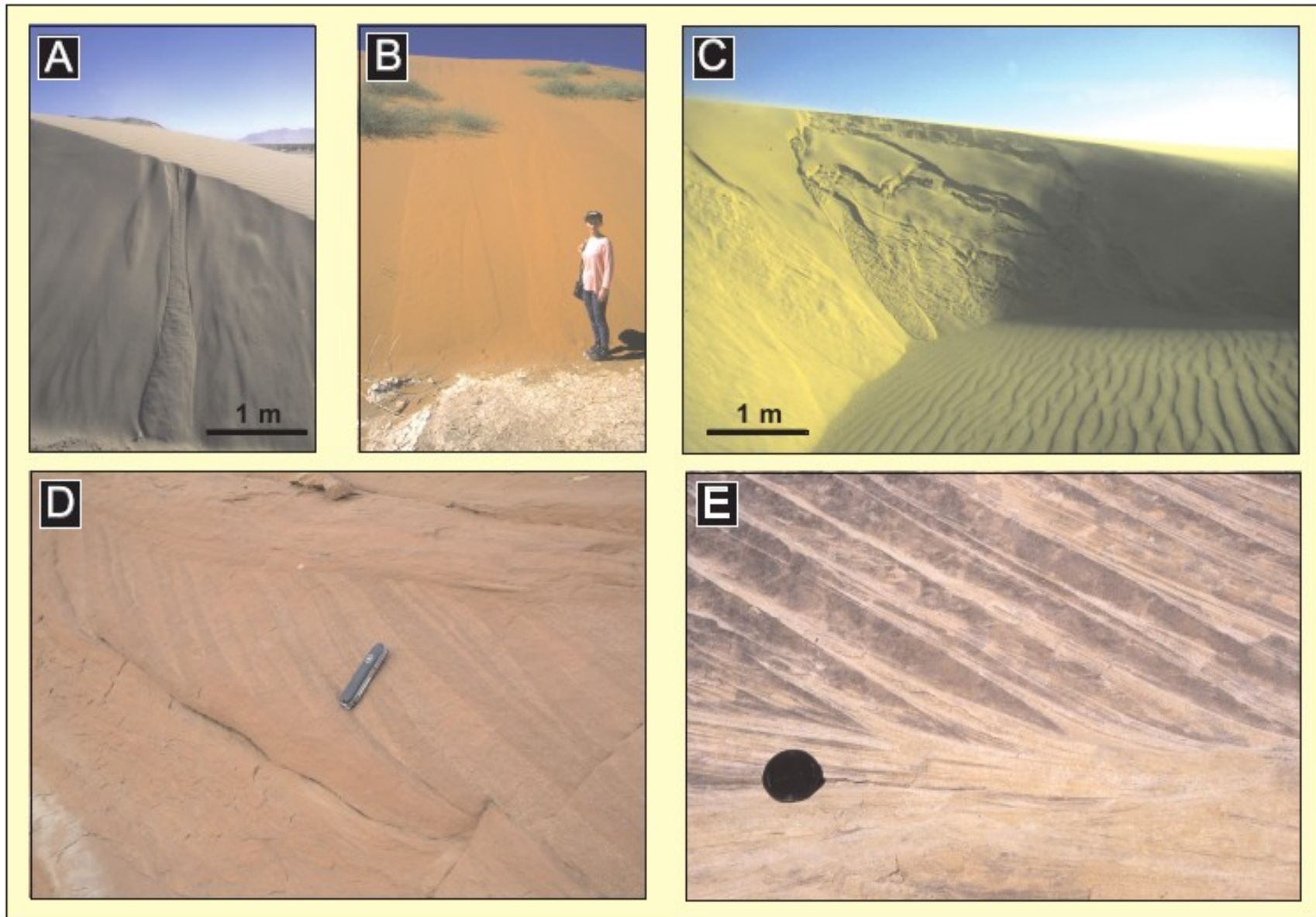


FIG. 18.—Examples of eolian grainflows and the characteristic strata that they produce. **A)** Scarp-recession grainflow, Namibia. **B)** Slump-degradation grainflows, Namibia. **C)** Slab slide failure degenerates downslope into a slump-degradation grainflow, Namibia. **D)** and **E)** Grainflow tongues pinching out into wind-ripple strata. Cedar Mesa Sandstone, Permian, Utah, U.S.A.

Chuva de grãos

Repouso da areia em saltação

Laminação fina inclinada na frente da duna

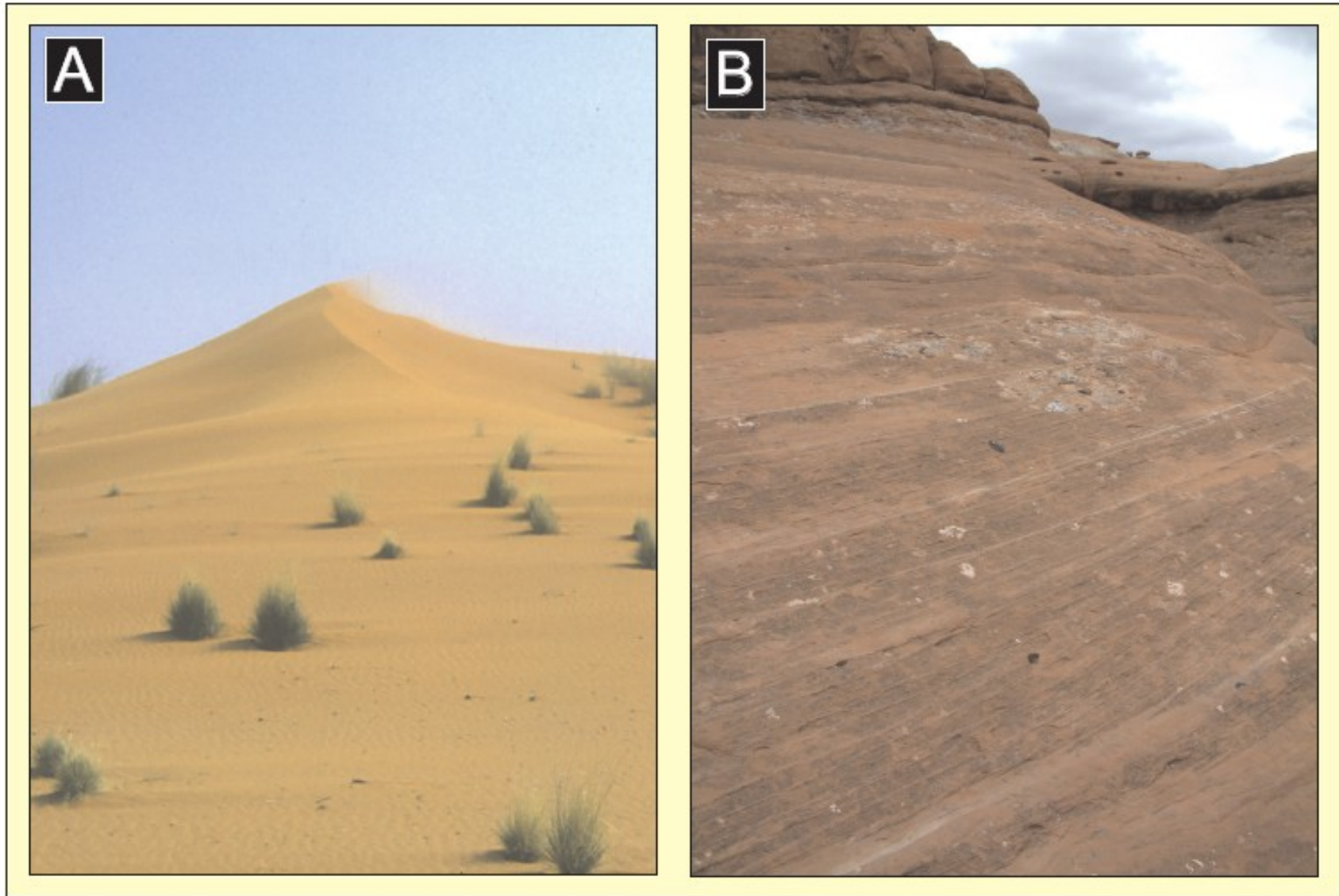


FIG. 19.—Examples of eolian grainfall and the characteristic strata that it produces. **A)** Saltation of sand-size particles over the brink of a dune to form a suspension cloud. Deceleration of the airflow in the lee-side depression results in a loss of carrying capacity, and the grains fall onto the upper part of the lee slope as grainfall deposits. Kalahari Desert. **B)** Grainfall facies interbedded with wind-ripple strata. Individual grainfall units rarely exceed 5 mm in thickness but tend to be laterally continuous along the strike of the cross-bedding for several meters to tens of meters. Interbedded units of wind-ripple strata are thicker (1–2 cm). Cedar Mesa Sandstone, Permian, Utah, U.S.A. Penknife for scale.

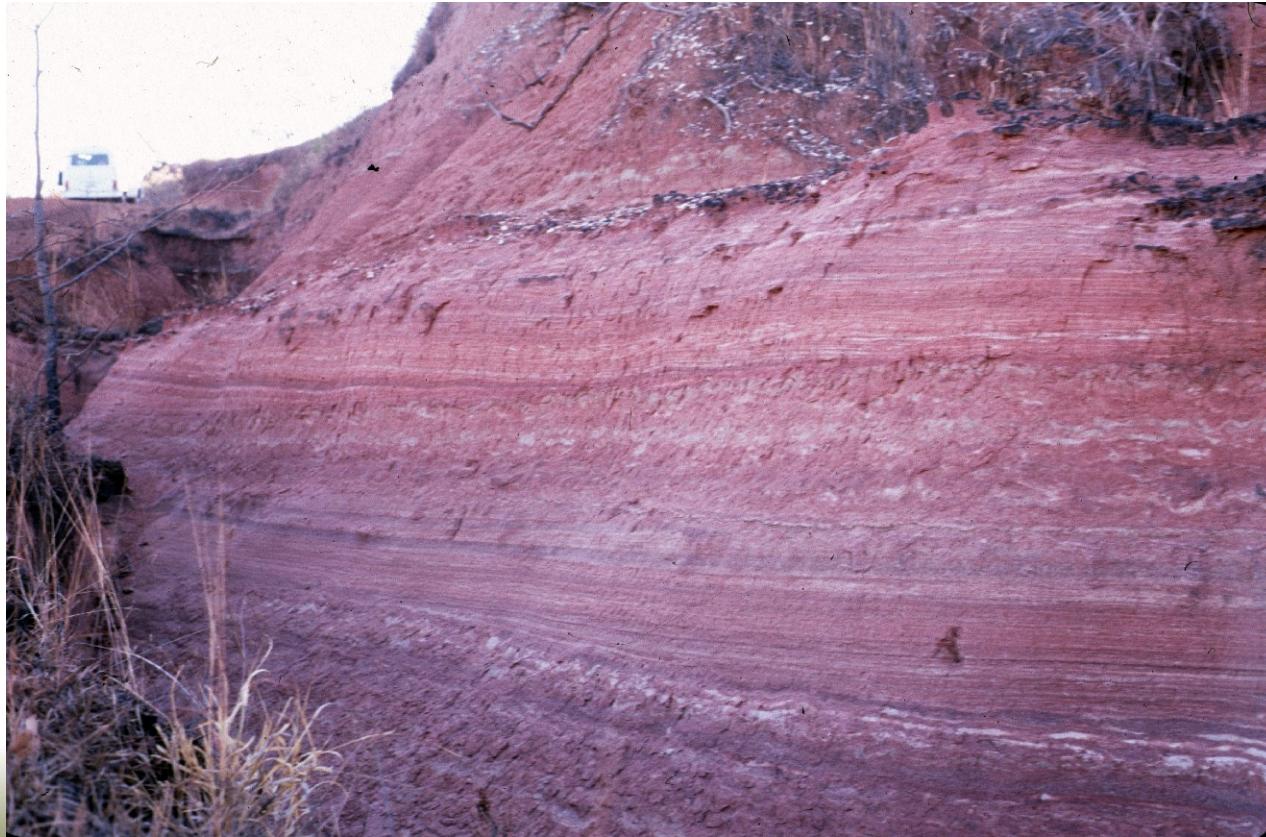
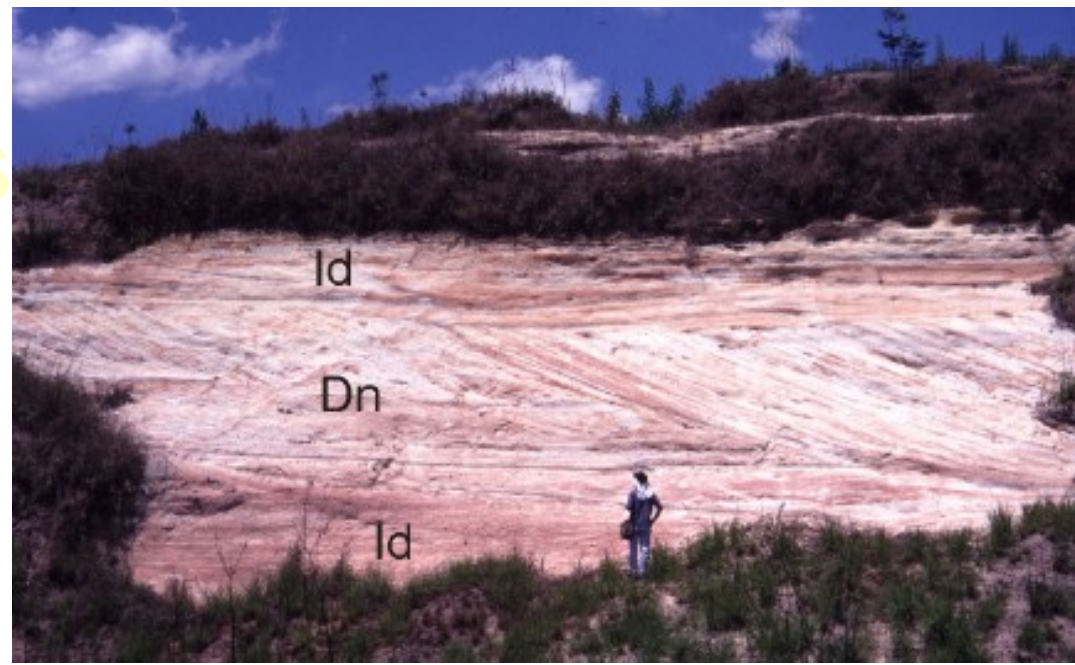
Fácies de dunas



Fácies

vegetação

Fácies de interdunas



Leito

Fácies

Arquitetura

Pré-
Vegetação

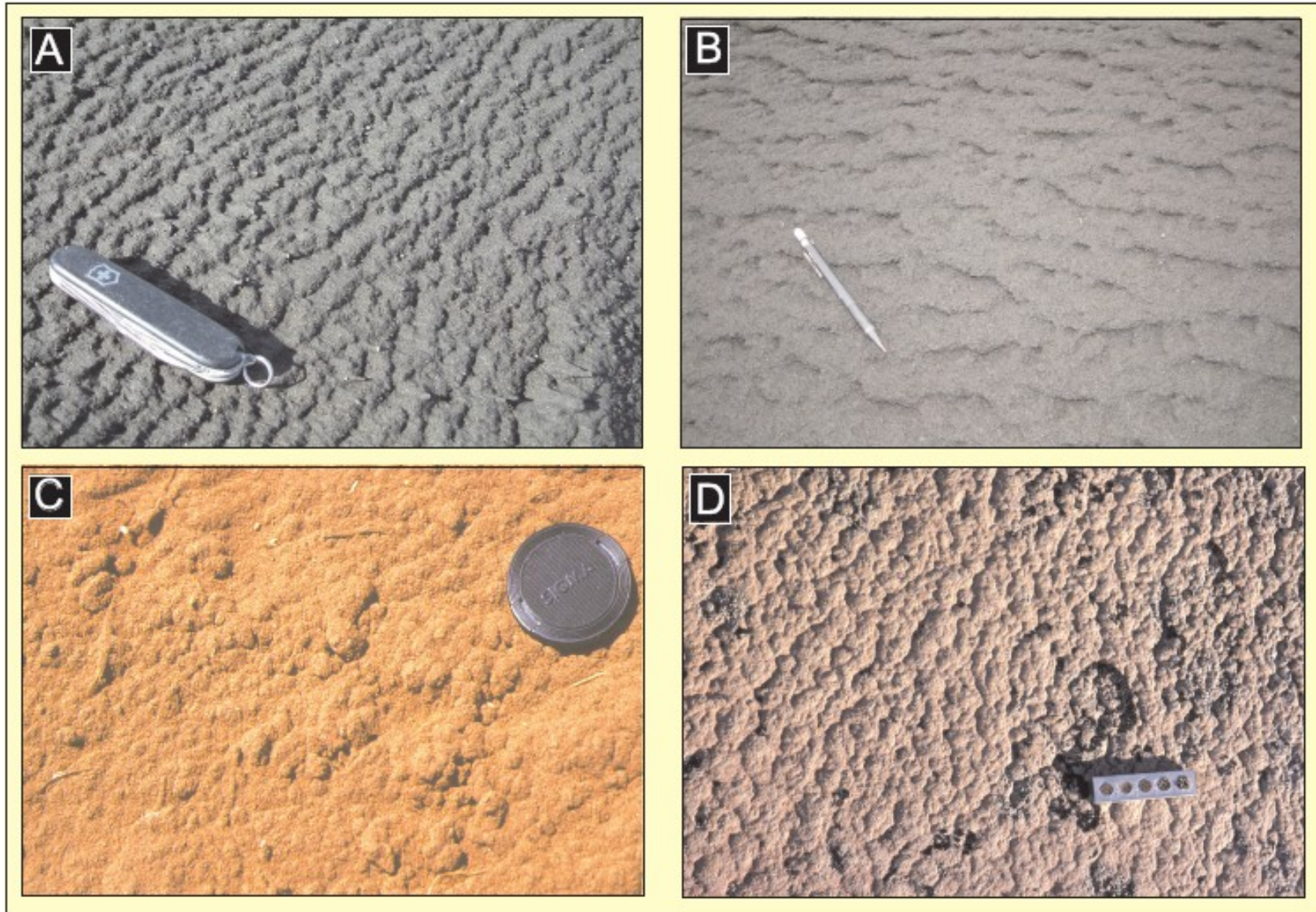


FIG. 20.—Examples of eolian adhesion ripples. **A)** Sólheimasandur, southern Iceland. Accretion occurs on the steeper upwind-facing slopes, and the “ripples” migrate upwind over time. **B)** Askja, central Iceland. **C)** Adhesion warts, Mojave desert. **D)** Adhesion structures on a bedding surface, Precambrian, Greenland (courtesy of John Collinson).

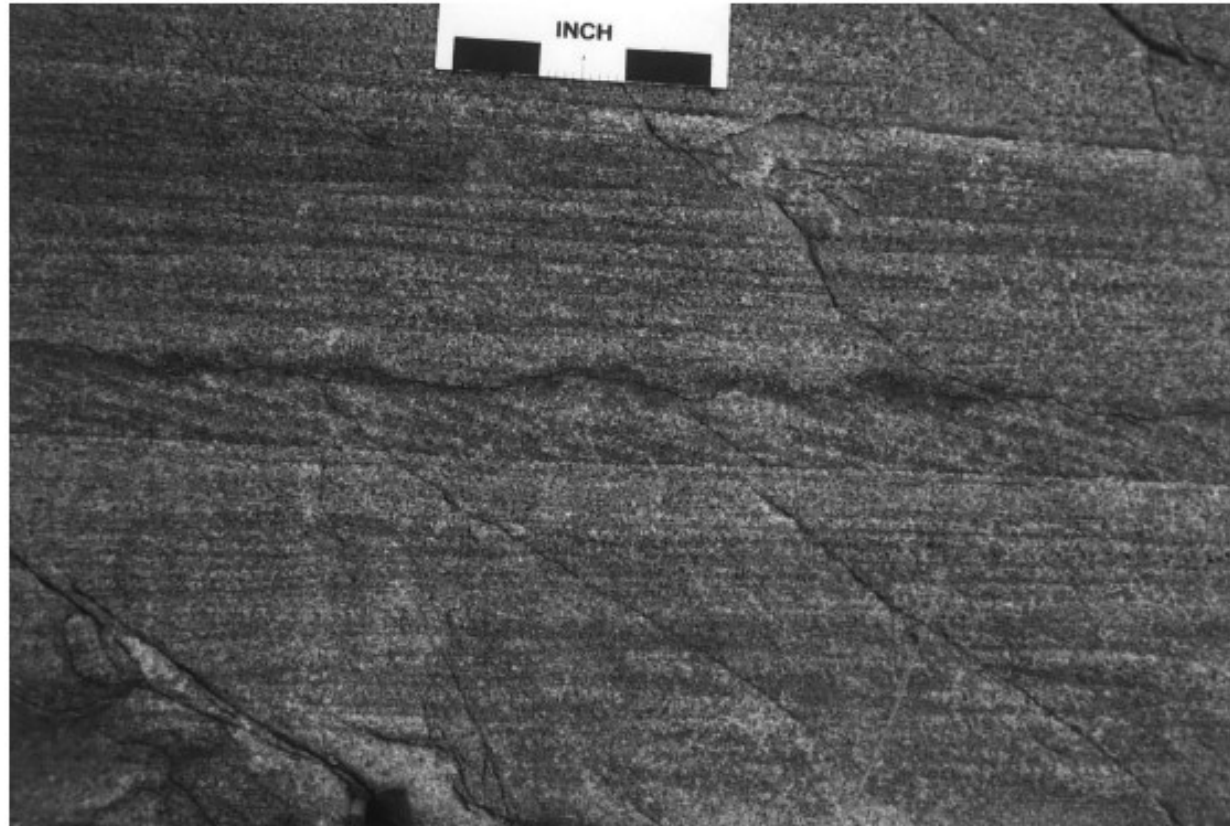


Fig. 5. Adherence ripple cross-stratification from the Whitworth Formation, Mount Isa Orogen, Australia, representing dune-plinth, sand-sheet or interdune deposits.

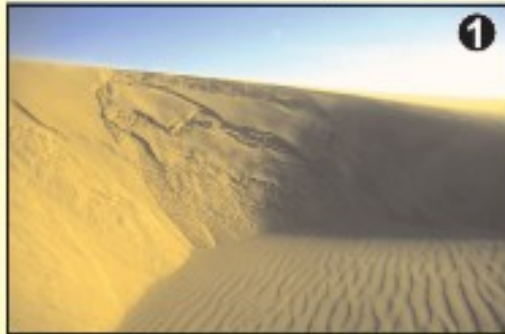
Eriksson & Simpson (1998)



Fig. 7. Adhesion ripples/warts from the Upper Mount Guide Quartzite, Mount Isa Inlier, Australia, preserved in a sand-sheet deposit.

Eriksson & Simpson (1998)

Modern examples



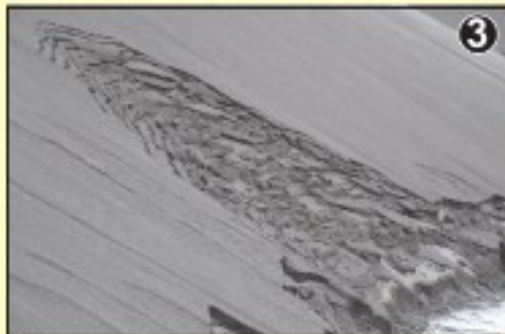
1

Slipface on barchan dune with grainflow avalanches. Wind ripples in dry interdune. Skeleton Coast, Namibia.



2

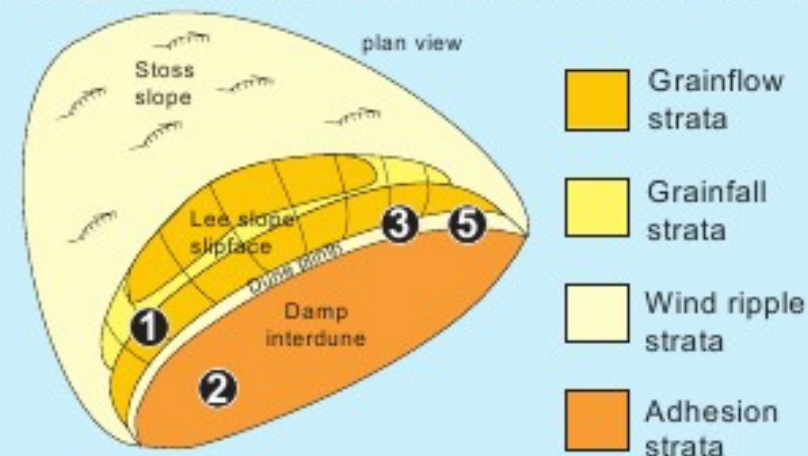
Adhesion structures on a damp interdune surface. Plan view. Monument Valley, northern Arizona.



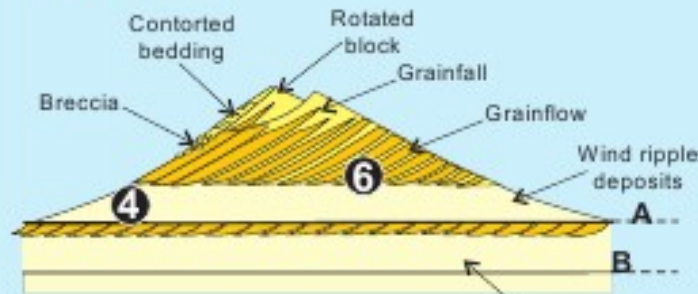
3

Slipface collapse due to cohesive slab slide. Stabs of wet sand fall without loss of internal structure. Askja region, NE Iceland.

Eolian facies distribution on crescentic dunes

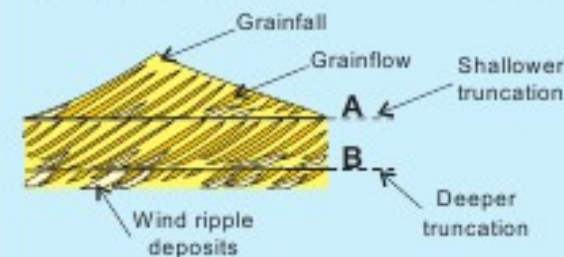


Large Dune



Only wind-ripple-dominated basal part of underlying dune set preserved

Small Dune

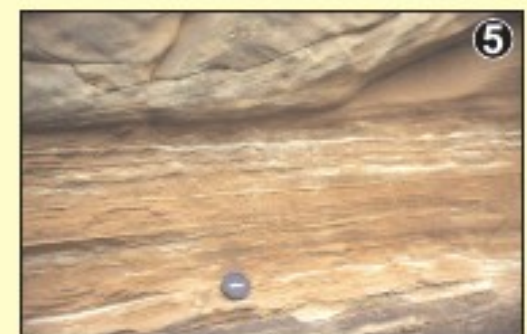


Ancient examples



4

Wind ripple strata in section displaying characteristic protraction lamination. Etjo Formation, NE Namibia.



5

Wavy laminae in damp interdune unit passing up into overlying wind ripple dune plinth strata. Helsby Sandstone, UK.



6

Grainflow tongues merging with wind ripple strata that represent dune plinth deposits. Cedar Mesa Sandstone, Utah

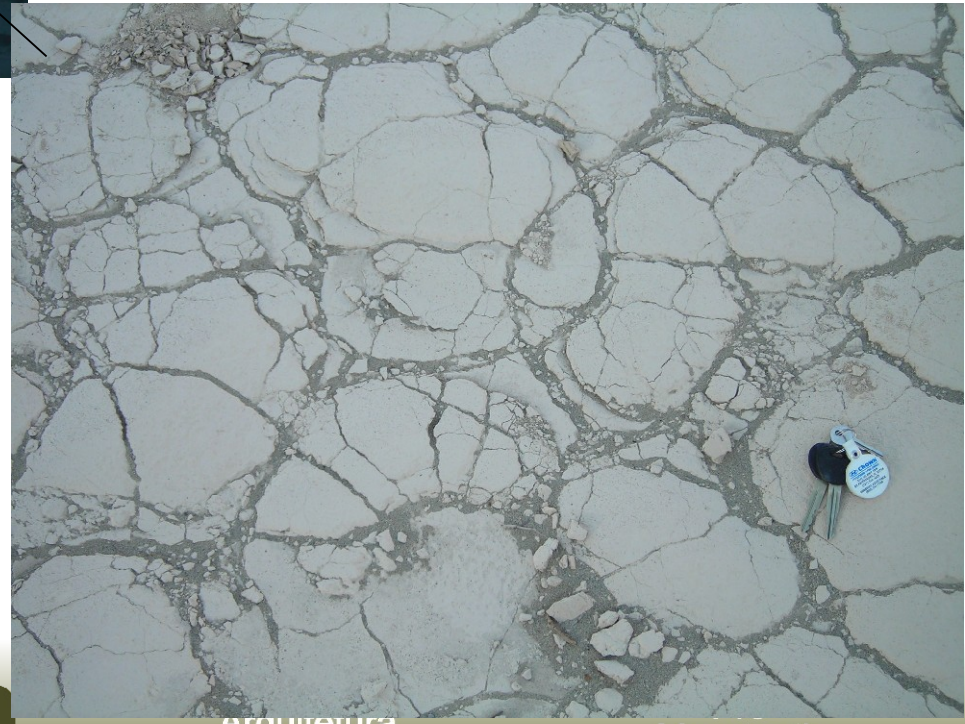
FIG. 21.—Examples of characteristic eolian facies and their distribution on a simple crescentic (barchan) dune and on large-scale and small-scale eolian dunes truncated to different levels (A, B). Level of truncation influences the preservation of facies types in the geological record, with features characteristic of the upper slipface lost. Modified after Kocurek and Dott (1981).

Depressão interdunar



Gretas de contração

Interação eólico-fluvial



Lençol de areia

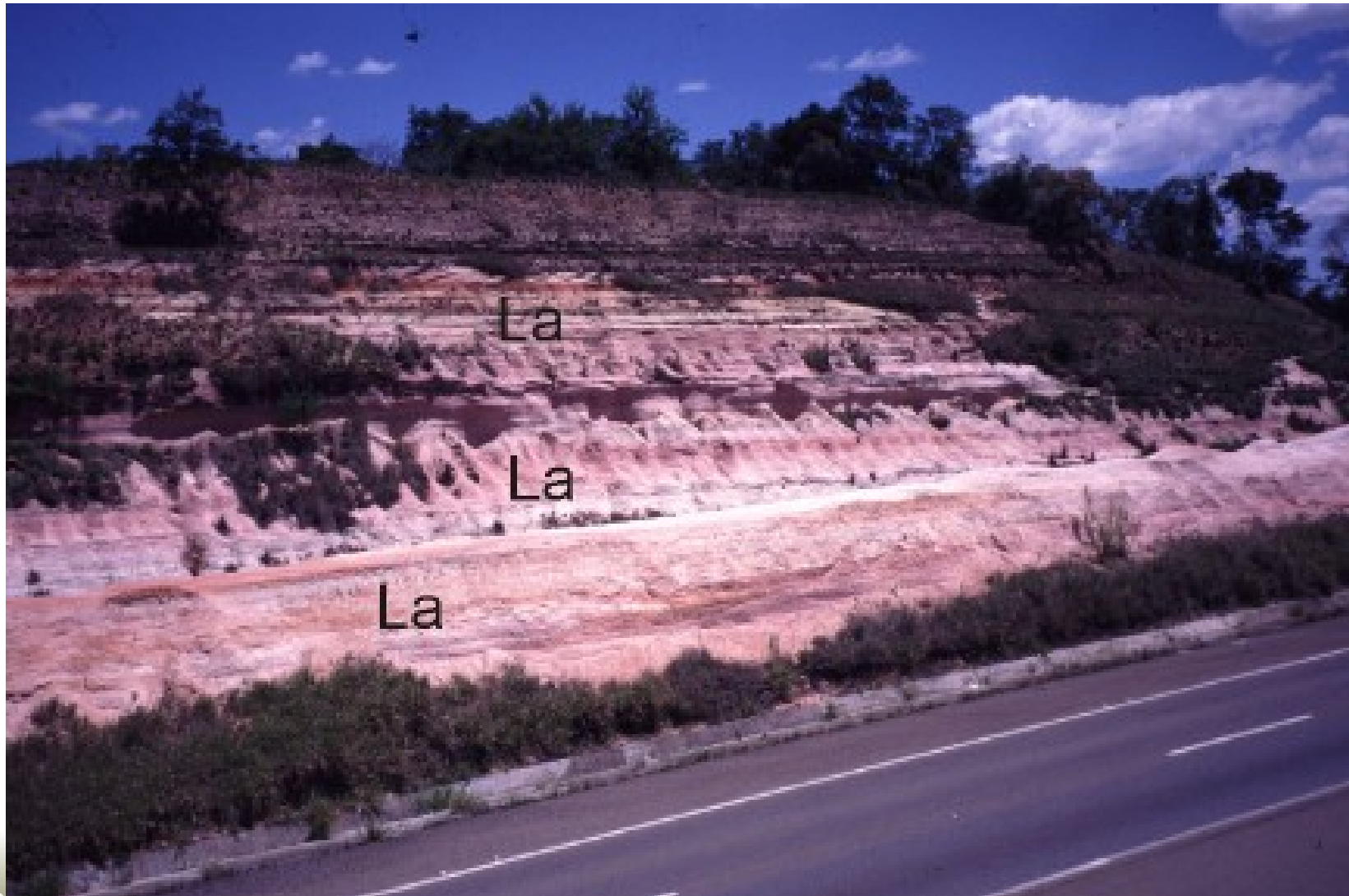
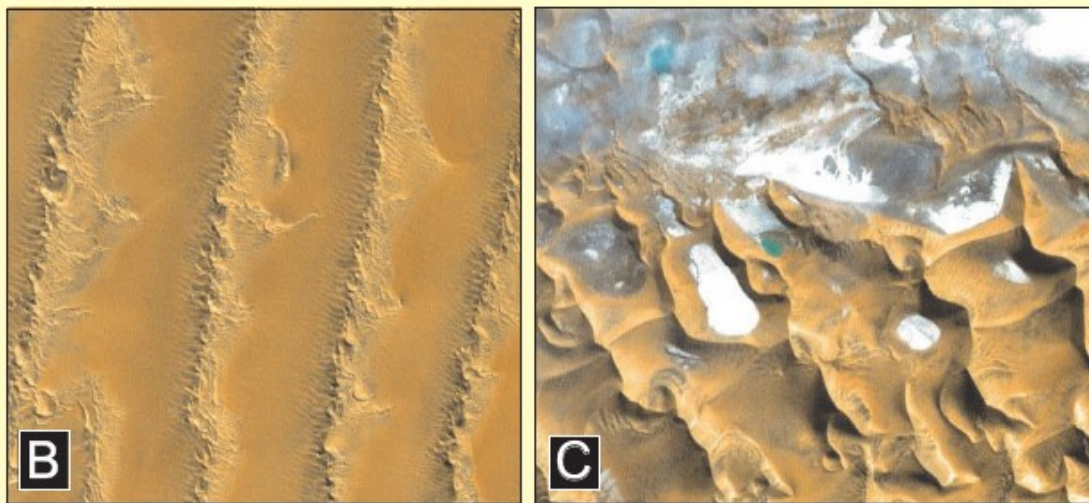




Image of part of the central Namib Desert. A) Separate elements composed of morphologically distinct bedform types are evident. B) Complex linear draa with superimposed transverse dune ribs. Net sand transport is from SSW to NNE. C) Mosaic of pyramid star draa with isolated interdune hollows. White color represents salt and calcrete deposits, green color represents ponded water in wet interdunes. Image courtesy of NASA Earth Observatory collection.

Mountney (2006)



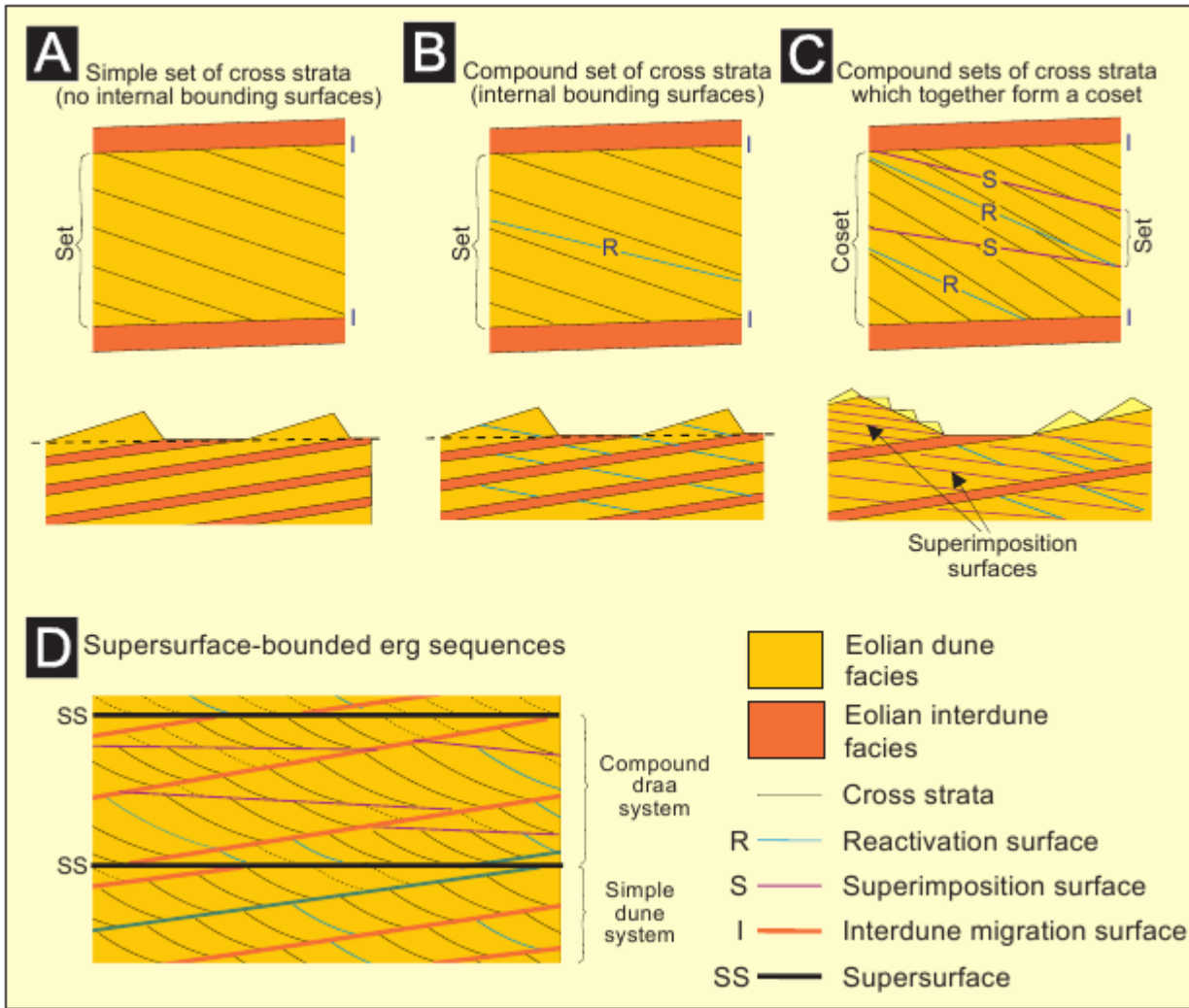


FIG. 30.—Models illustrating the geometry of reactivation surfaces, superposition surfaces, interdune migration surfaces, and supersurfaces in eolian systems. The hierarchical nature of the bounding surfaces, as described by Brookfield (1977), is not always readily identifiable in the rock record. The surfaces do not necessarily break into universally distinct groups by extent or dip angle.

However, higher-order bounding surfaces always truncate lower-order bounding surfaces. Modified after Kocurek (1991).

Mountney (2006)

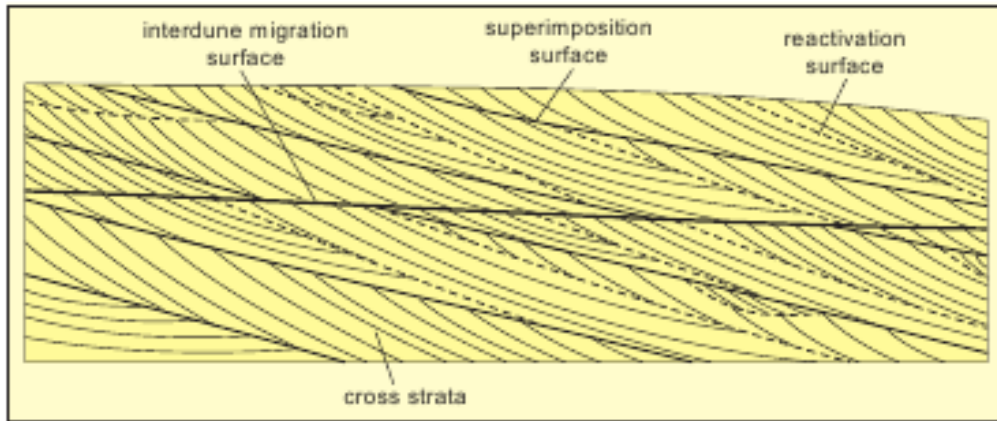


FIG. 31.—Definition diagram for the hierarchical system for describing eolian bounding surfaces in compound-cross-bedded sands and sandstones, as proposed originally by Brookfield (1977). Interdune migration surfaces arise as a consequence of dune migration. Superimposition surfaces represent the migration of superimposed bedforms and/or scour pits over a larger parent bedform. Reactivation surfaces represent partial deflation of a bedform lee slope and arise in response to periodic changes in bedform migration direction, steepness, speed, and/or asymmetry.

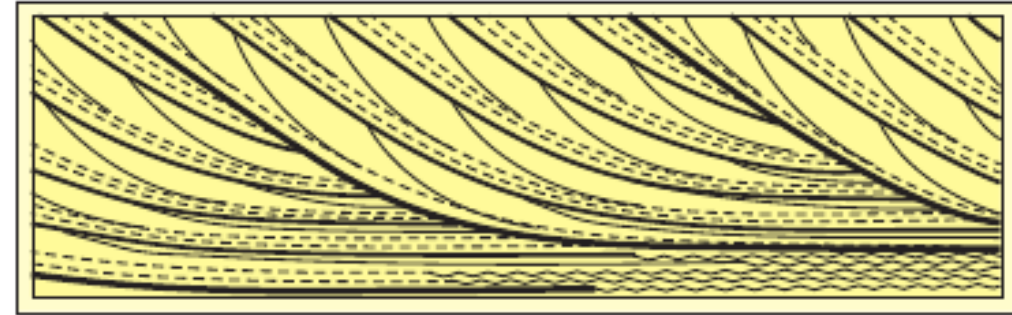


FIG. 32.—Schematic diagram illustrating a co-set of scalloped cross strata with internal cyclicity. Two distinct scales of bounding surface are evident within the co-set. Note how bounding surfaces at the base of the sets pass down dip into corrugated surfaces. This relationship, which can potentially occur at a variety of scales, is indicative of eolian dune migration that occurs synchronously with accumulation in damp, water-table-controlled interdunes. Based on observations from the Jurassic Entrada Sandstone, NE Utah, U.S.A. Modified from Crabaugh and Kocurek (1993).

Mountney (2006)

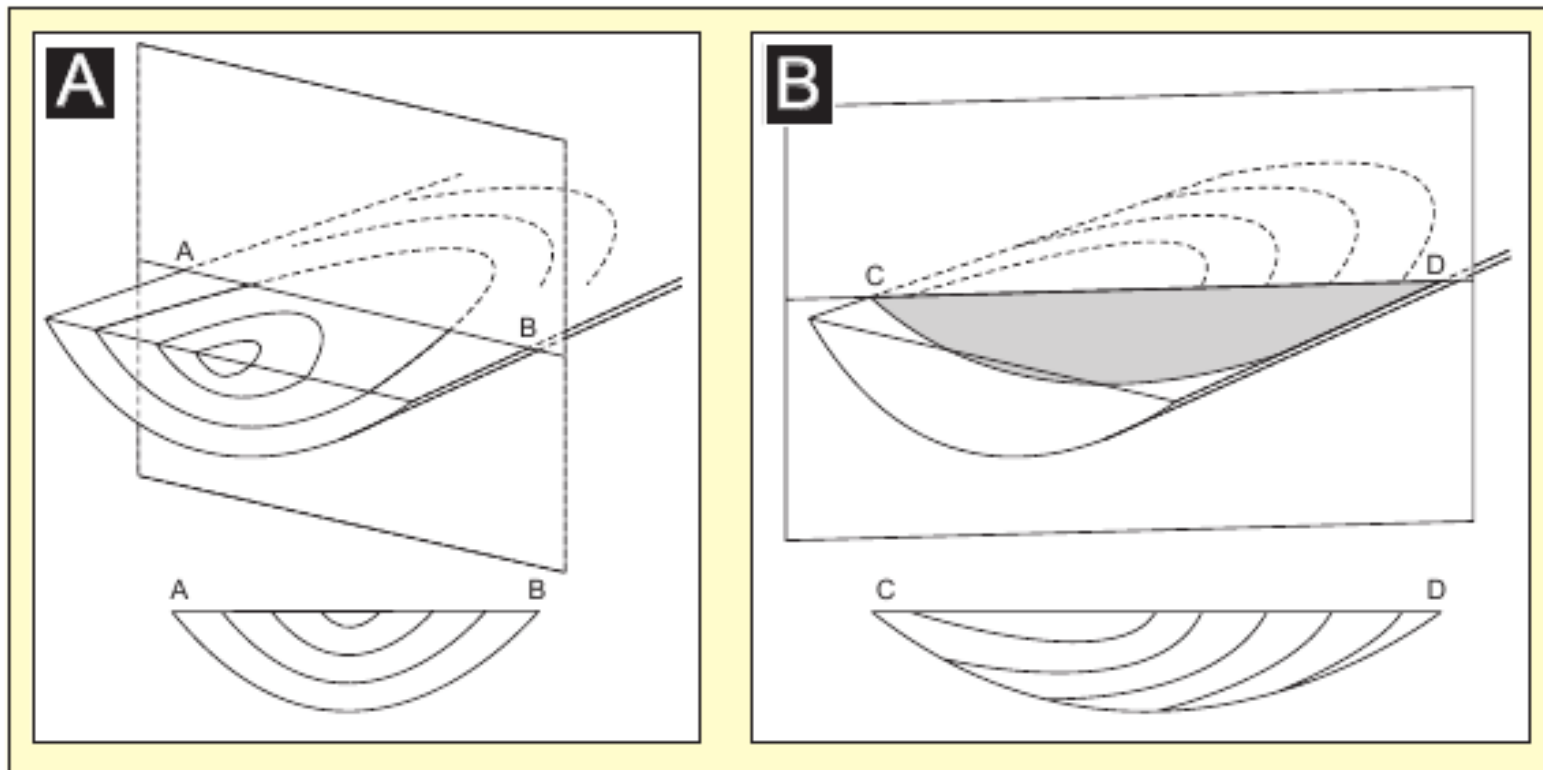


FIG. 34.—Schematic illustration of the geometric complexity of trough-cross strata. **A)** A vertical section oriented transverse to the trough axis reveals symmetrical cross-stratification planes that are apparently concordant with the trough base. **B)** A vertical section oriented oblique to the same trough axis reveals cross-stratification planes that apparently fill the trough asymmetrically and downlap onto its base. This illustrates the problems associated with the measurement of foreset dip azimuths from core or outcrop for the purposes of establishing paleo-transport direction from trough-shaped cross strata. Modified after DeCelles et al. (1983).

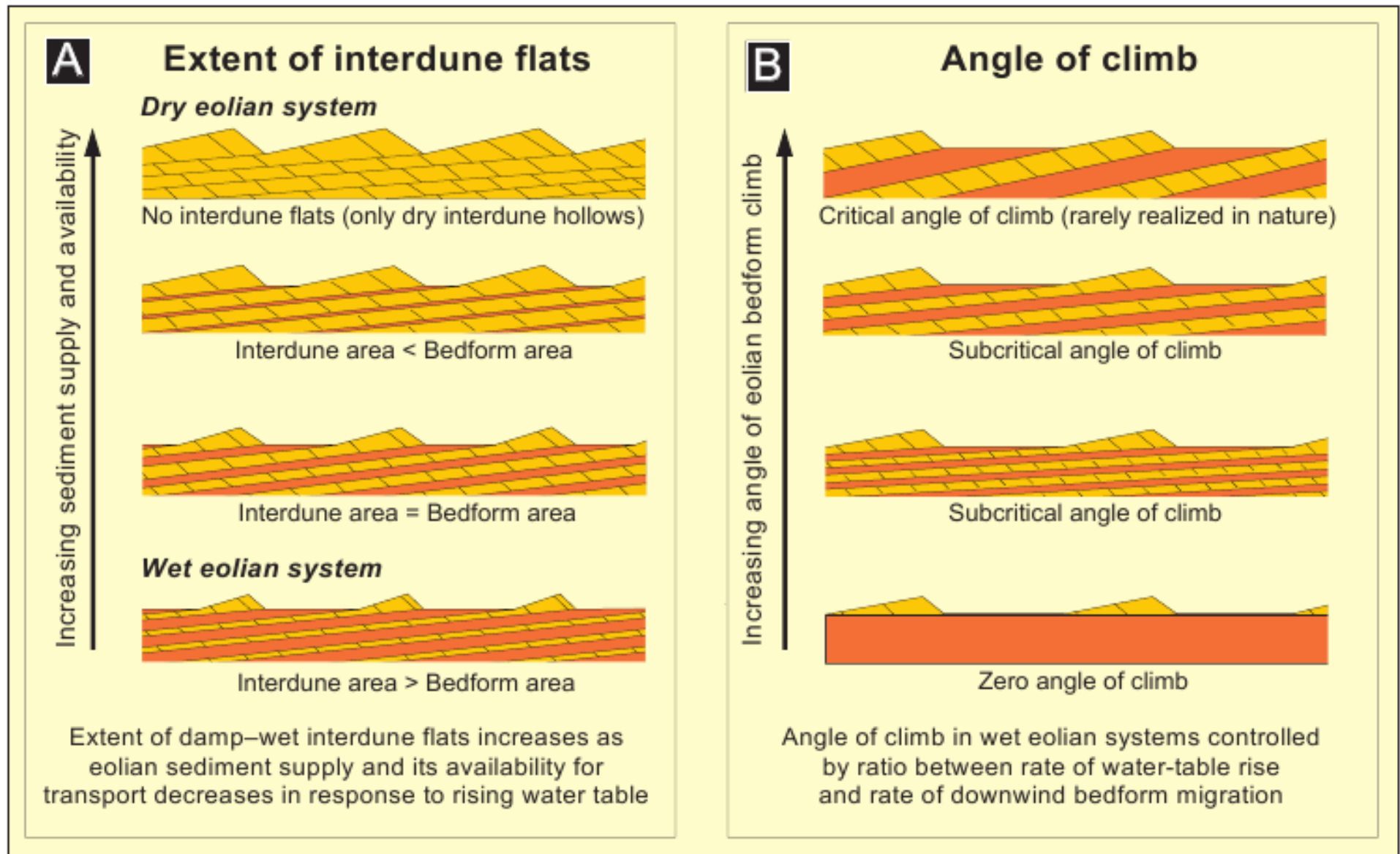


FIG. 61.—Basic controls on interdune geometry in wet eolian systems. Modified in part from Kocurek and Havholm (1993).

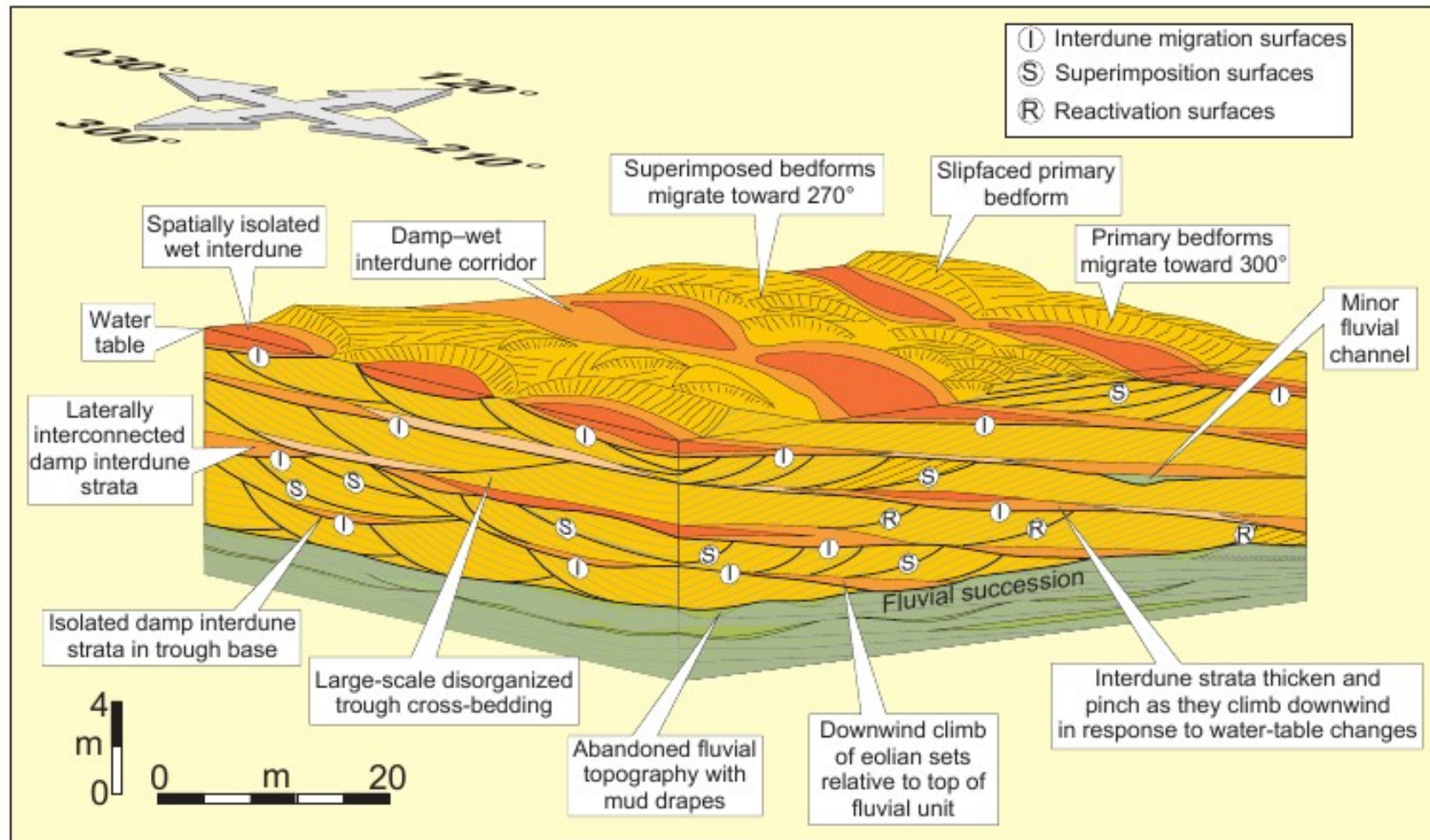


FIG. 55.—Depositional model for the Triassic Helsby Sandstone Formation, Cheshire Basin, UK. Dune elements climb downwind, as do adjacent interdune elements, which exhibit downwind facies variability that reflects subtle changes in the level of the water table relative to the accumulation surface during accumulation. Lateral connectivity of the interdune elements is controlled by dune morphology, and both isolated interdune hollows (ponds) and interconnected, throughgoing corridors are recognized. Modified after Mountney and Thompson (2002).

Eólico Pré-Cambriano

Mais antigos depósitos eólicos - . 2.1 Ga Deweras Group (Zimbabwe) and Hurwitz Group I (Canada).

Diversos exemplos a partir de 1.8 Ga

Ausência de depósitos arqueanos e escassez pré 1.8 Ga -

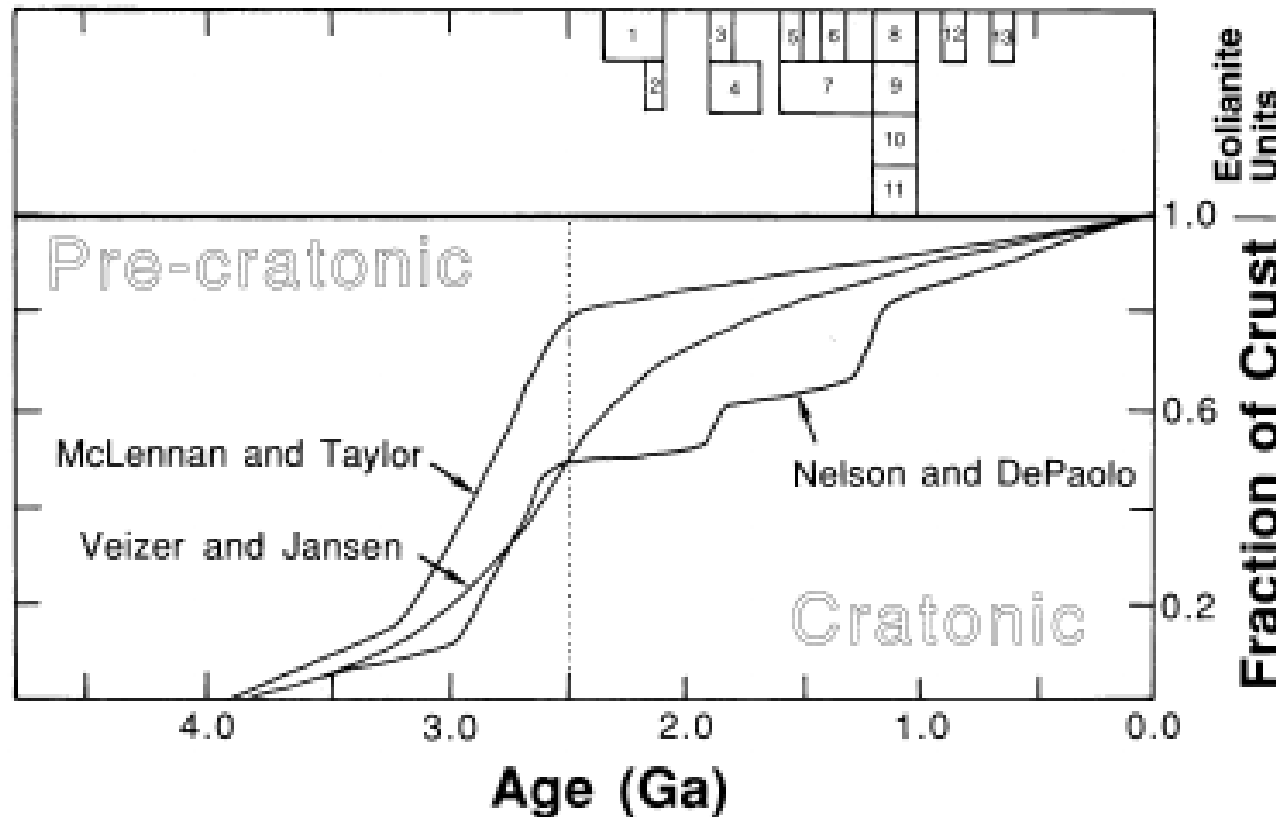
- crescimento crustal

- atmosfera menos densa? Não – depósitos fluviais implicam em chuva desde o

Arqueano

- não reconhecimento

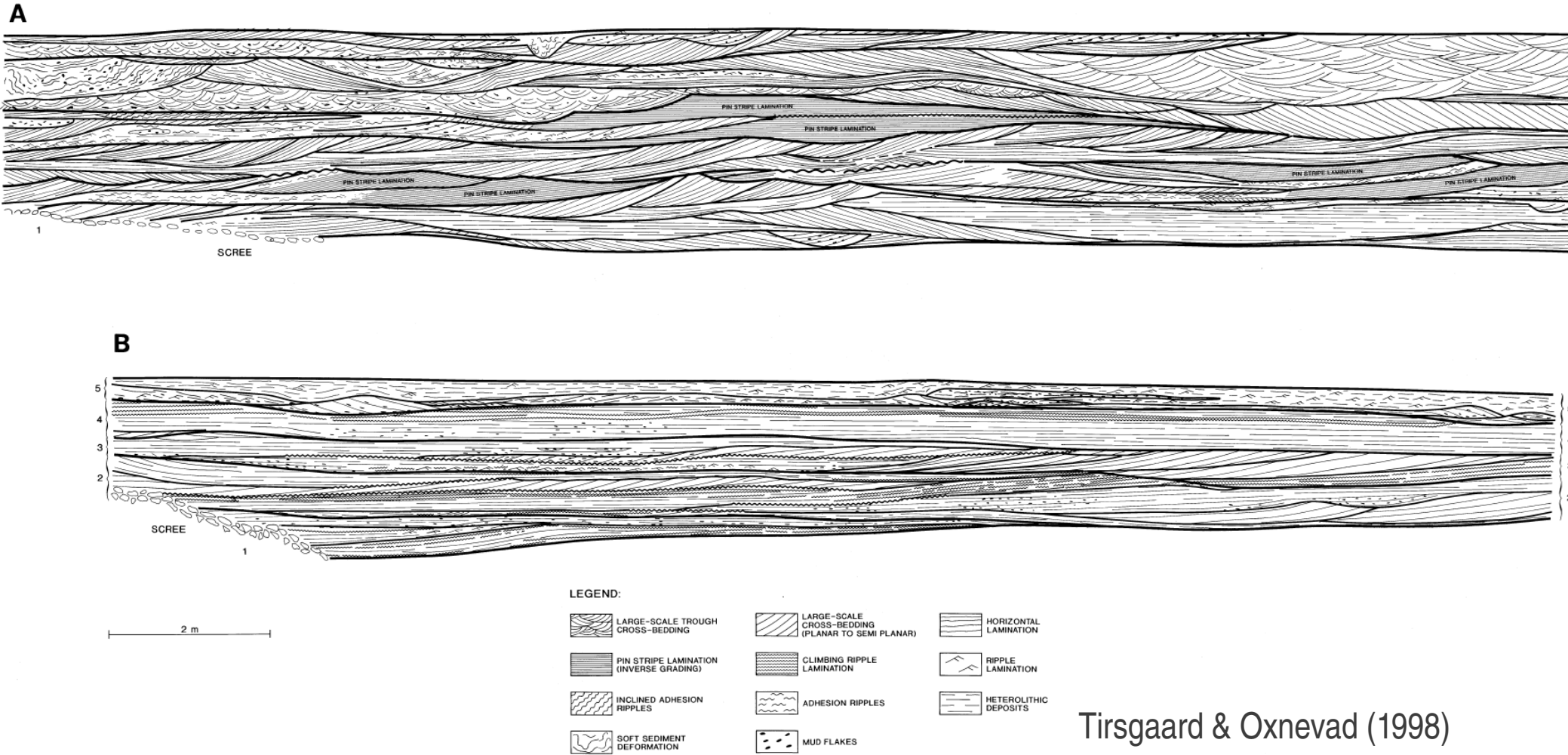
Abundância após 1.8 G.a. - estabelecimento dos ciclos de supercontinentes.



Eriksson & Simpson (1998)

Crustal growth models and temporal distribution of eolian deposits; ages of deposits are rounded to 100 million years. Precratonic (greenstone) sedimentary successions dominate the pre-2.5-Ga record. Cratonic sedimentary successions are mostly younger than 2.5 Ga. Curves are from Veizer and Jansen (1979), McLennan and Taylor (1982) and Nelson and DePaolo (1985). Eolianite units shown and the sources of their ages are: 1 D Hurwitz Group, Canada (Aspler et al., 1992); 2 D Deweras Group, Zimbabwe (Master, 1991); 3 D Makgabeng Formation, South Africa (Tankard et al., 1982); 4 D Mount Isa Inlier, Australia (Page, 1983a,b); 5 D Hornby Bay Group and Thelon Formation, Canada (Ross, 1983a,b; Jackson et al., 1984); 6 D Dala Sandstone, Sweden (Patchett, 1978); 7 D Nebraska subsurface, U.S.A. (Carlson et al., 1992); 8 D Hazel Formation, U.S.A. (Walker, 1992); 9 D Calyie Formation, Australia (Goode and Hall, 1981); 10 D Copper Harbor Formation, U.S.A. (Taylor and Middleton, 1990); 11 D Mancheral Quartzite and Venkatpur Sandstone, India (Chakraborty, 1991; Chakraborty and Chaudhuri, 1993); (12) Bakoye 3 Formation, Morocco (Deynoux et al., 1989).

- Preservação de depósitos eólicos pré-vegetação
 - Ocorrência mais abrangente (vegetação ausente)
 - Preservação – controle climático?



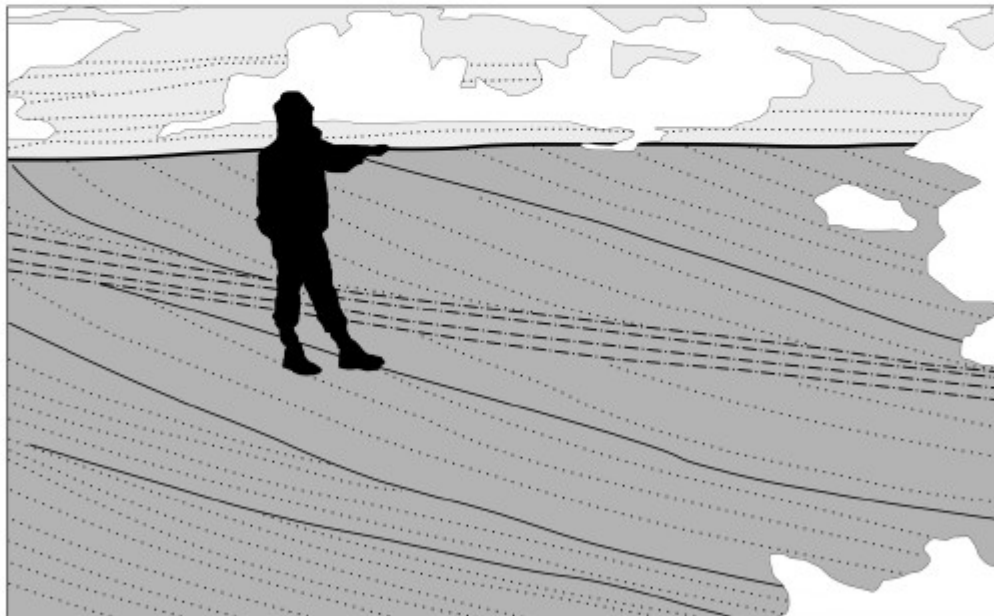
Tirsgaard & Oxnevad (1998)

Fig. 5. (A) Lateral profile of Type I and Type II sand sheets (location is shown in Fig. 2). The profile shows six stacked sand sheets of which 5 and 6 are Type I sand sheets dominated by medium-scale trough cross-bedding. Sand sheets 1-4 are of Type II, showing the typical interbedding of aeolian and fluvial deposits, with aeolian deposits being preserved preferentially on the lee side of fluvial cross-beds. Type II sand sheets are dominated by low-angle and high-angle tabular cross-strata. (B) Multistorey sheet sandstone body consisting of five stacked Type III sand sheets showing the typical architecture of these sand sheets, with relatively planar lower set boundaries and dominance of planar-parallel lamination and climbing ripple lamination with some low-angle cross-strata.



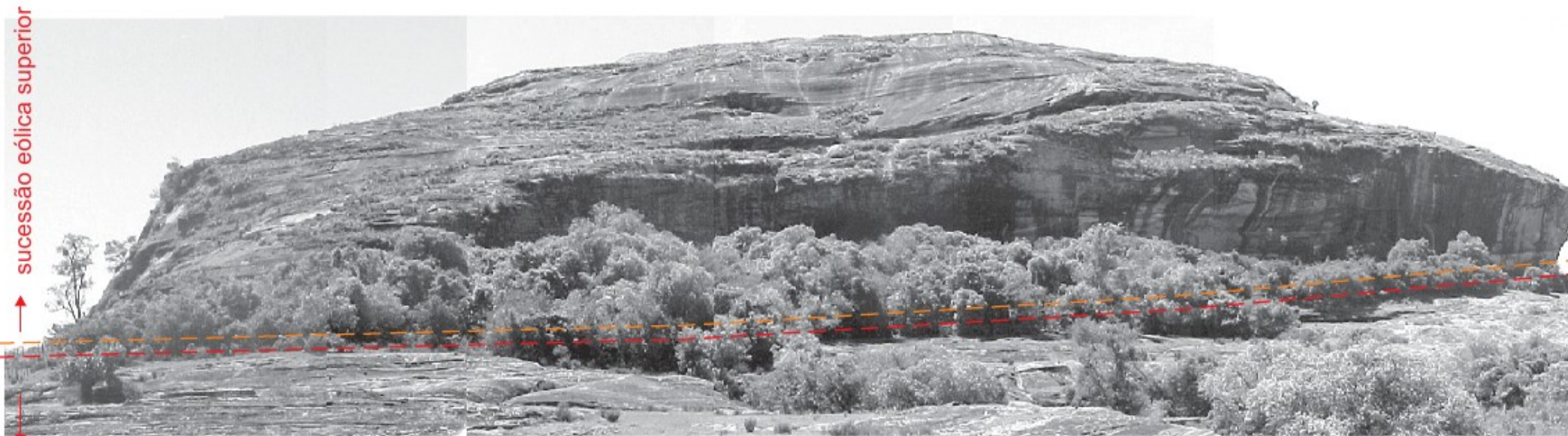
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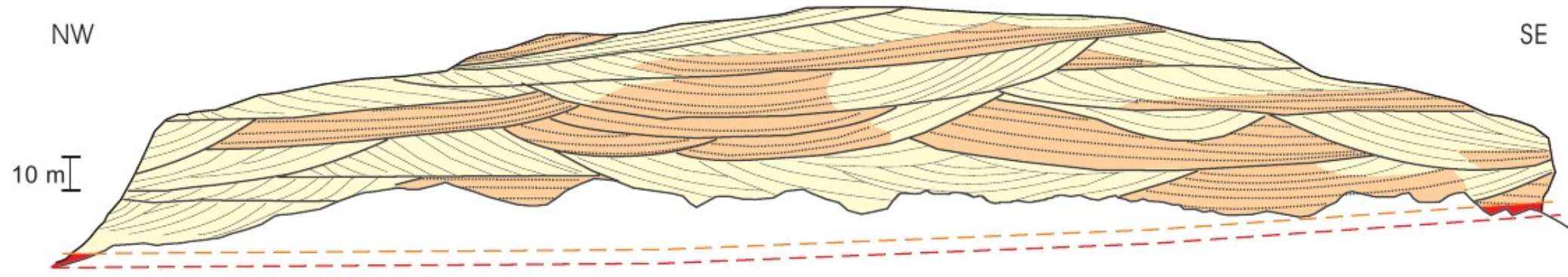
- Interdune deposits
- Eolian dunes deposits
- 1st order surfaces
- 2nd order surfaces
- 3rd order surfaces
- Depositional surfaces

Fig. 7 – Photomosaic of the eolian dune field facies association showing the relationship between dune and interdune deposits and the main bounding surfaces. Note the 2nd order surface that allows relating the dune deposit to a



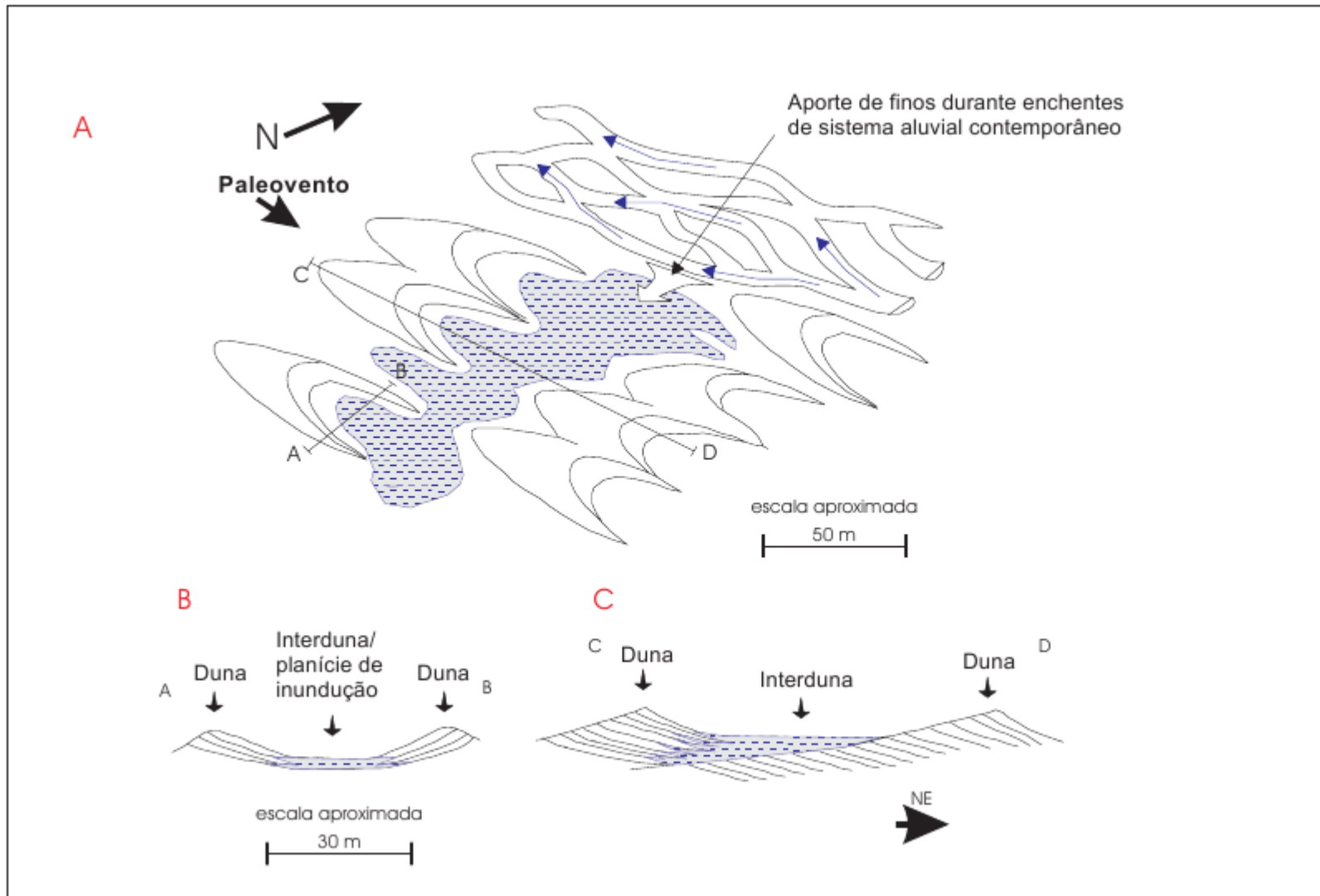
sucessão eólica superior

sucessão eólica inferior



- Superfícies de 1º ordem - cavalgamento de dunas ou interdunas sobre dunas
- Superfícies deposicionais de interdunas úmidas
- Superfícies deposicionais (estratos frontais de dunas) e de 3º ordem (reativações)
- - - - Superfícies de reinício da deposição eólica (S4D)
- - - - Supersuperfície, afogamento do campo de dunas (S4C)

- Associação de fácies de dunas eólicas
- Associação de fácies de interdunas-planícies de inundação
- Associação de fácies flúvio-lacustres



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