Introduction to eolian deposition and production
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An review of basic principles of eolian deposition, with illustrations from the modern and ancient sediments.

The Interior; Watercolour of Oman by S.G. Fryberger
Dynamic sand sea sedimentology model:
Distinct facies of eolian sand seas stack through lateral migration

From Porter, 1986

Aeolian sand seas as a whole may have facies belts based on net sand sea migration, or net evolution.
Eolian sand sea formation:

Wind, topography, and sediment supply interact to deposit sand seas over long periods of time, commonly in an on-again, off-again manner.

Figure 2 - Theme and variations on topographic traps for drifting sand. (1) Lee zone, (2) very shallow basin on desert floor, (3) wind weakens against obstacle, (4) loss of resultant wind energy near topographic uplands due to deflection of winds, (5) loss of resultant wind energy near an upland due to downslope (katabatic) winds. To a certain extent, this mechanism is found at Great Sand Dunes in the form of the east winds that blow back the dunes.
Eolian sand sea formation: Depending upon distance of sand migration from source, trap-biased or source-biased sand seas will form.
Eolian sand sea creation
Complex interactions of wind, rainfall belts, and water bodies also can create and define sand seas

Minnelusa model?

Mauritania
Eolian deposits are built from four facies groups: Dune, interdune, sand sheet and sabkha.
Rapid changes in eolian facies can occur within a single oil or gas field, influencing recovery factors.
Basic Dune Forms are *barchan, linear and star*
They result from differences in wind regime.
Dune sub-types have distinct stratification styles. Result of morphology and process framework

- **Reversing Dunes**: Arrows show wind directions.
- **Linear Dunes**: Arrows show probable dominant winds.
- **Star Dunes**: Arrows show effective wind directions.
- **Blowout Dunes**
- **Barchan Dunes**: Arrow shows prevailing wind direction.
- **Parabolic Dunes**: Arrow shows prevailing wind direction.
- **Barchanoid Ridge**: Arrow shows prevailing wind direction.
- **Dome Dunes**
- **Transverse Dune**: Arrow shows prevailing wind direction.

*Figure 1. Dune forms produced in unidirectional wind regimes, from the classification of McKee (1979), include parabolic, barchan, barchanoid, and transverse dunes. Dome dunes are embryonic forms of other dunes, such as barchan. Blowout dunes are comparable to parabolic, but without the parabolic “arms” (from McKee, 1979).*

**Barchanoid dune sub-types**
Idealized barchan dune cross-section along the wind:

Drawing shows geomorphic, structural and genetic terms.
It is important to keep distinction clear in core description.

*Always start with genetic terms, the least interpretive description*
Eolian stacking patterns can be complex
Eolian bedforms rarely stack in complete sequences

The cartoon world . . .

The real world . . .
Ancient example Navajo Sandstone: eolian sequences represent the stacking of only portions of dunes, or other eolian facies.
Internal stratification of aeolian dunes is a direct reflection of the wind regime and the growth seasons of the dune.

Studies of modern dunes shows that cross-bedding patterns are probably complex in the subsurface.

Nebraska Sand Hills, barchanoid dune

Libya, Linear dune
**Eolian primary strata**

The type of primary eolian stratum is an important control on reservoir permeability. Drivers: texture, mineralogy, cements of strata types.

- **Avalanche and grainfall:** well sorted, largest grains
- **Dry interdune and sabkha:** evaporites and clays, poor sorting

**Very good reservoir**

- Ripple, moderate sorting, pin stripes reduce vertical permeability

**Bad reservoir**

![Figure 6 - Primary eolian strata and origins. A: avalanche, B: grainfall, C: ripple, D: adhesion strata. Both Fig. 5 and 6 after Feyberger, et al., 1981.](image)
Eolian primary strata types are defined by process and wind

**Process:** mass flows versus ballistic effects with ripples, and grainfall through still air in lee of dune

Wind direction and strength variability, many time scales minutes, hours, days, months, years
Dune strata commonly have better poroperm characteristics than interdune or extradune strata.

GRAPH OF POROSITY VERSUS PERMEABILITY, showing delineation of three known environments of deposition. Values were obtained each foot from 630 feet (192 m) of core of the Weber Sandstone from three wells in the Brady field, T. 16 N., R. 101 W., Sweetwater County, Wyoming, U.S.A. A grid was superimposed over the plotted data, and the number of points within each square was counted and assigned to the center of each square. Those points are data points for contours (Fig. 162.)
Primary strata occur as bundles in dunes and interdunes: Differing permeabilities may cause sweep inefficiency

Fig. 18. Hypothetical, downwind-climbing, sinuous-crested eolian dune and interdune sequences. Note lateral and vertical variability in stratification type, preferred permeability components, and interdune barrier continuity. Cross-sections are in Fig. 19.

After Lindquist, 1988
Key permeability directions

Always use data from core and dipmeter when planning secondary operations

After Krystinik, 1990
Core example from Permian Rotliegend Fm. Auk Field, North Sea
There is a strong permeability contrast between ripple and avalanche strata

- Tight, red-bed ripple strata
- Porous, oil-stained avalanche strata
- White, cemented, tight ripple strata
Core example from Auk Field, Permian Rotliegend, UK North Sea

**Permeability contrasts compartmentalize eolian reservoirs at laminar scale**

Porous, permeable avalanche strata - oil saturated

Tight ripple strata – red-beds
Thin eolian sedimentary units can exist as highly permeable flow units.

Cambrian Amin Formation: Oman

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>4750</td>
<td>Sandflow toe</td>
</tr>
<tr>
<td>4775</td>
<td>Avalanche strata</td>
</tr>
<tr>
<td>4725</td>
<td>100-200 Md perm</td>
</tr>
</tbody>
</table>

4750 m depth +/-
Nugget Sandstone, Utah

Flow barriers are created by discontinuities of primary strata, as well as higher-order stratigraphic breaks

Fig. 19. Depositional-dip and depositional-strike hypothetical porosity cross-sections for Fig. 18. Grainflow deposits (plain) are arbitrarily assigned a porosity of 15%; grainfall and wind-ripple cross-strata (coarse stipple) 10%; and interdune deposits (fine stipple) 5%. Note lateral variability and compartmentalization in dune “layers” and potential communication between layers because of interdune erosional removal.

after Lindquist, 1988
Permeability anisotropy in the Nugget Sandstone
after Lindquist, 1988

Fig. 9. Dune–interdune facies resolution. The two lower dune cross-set cycles distinguishable from stratigraphic dipmeter data are not easily resolved by porosity and permeability data because they are of the indistinct grainflow texture with reservoir properties similar to their associated interdune deposits. Also note the unusual directional dip variability (SE azimuth) in the porous Nugget cross-strata of the top cycle.
Minnelusa core
Raven Creek Field
small scale heterogeneity

Oil stained sand
Anhydrite-cemented dune
New concepts for eolian reservoirs, illustrated by analogues from the modern Wahiba Sands of Oman

• Complex time-structure of Wahiba dune field, and therefore of ancient aeolian reservoirs.

• Build-and-fill model of aeolian reservoirs: implications for production.

• Re-cycling of aeolian sand into fluvial deposits: importance of sediment pedigrees.

• Common existence of thin, highly permeable eolian thief zones that reduce sweep efficiency.

The Wahiba Sands, Oman
The Wahiba Sand Sea has a complex time-structure. Discontinuous deposition, incomplete preservation.

Age dates from the Wahiba Sands:

- 112 Ka
- 229 Ka
- 25 Ka
- 150 Ka
- 10 Ka
- 2 Ka
- 10-23 Ka
- 8 Ka
- 32 Ka
- 36 Ka
- 40 Ka
- 110 Ka
- 112 Ka
- 150 Ka
- 229 Ka
- 25 Ka
- 10 Ka
- 2 Ka
- 10-23 Ka
- 8 Ka
- 32 Ka
- 36 Ka
- 40 Ka
- 110 Ka

Wadi Batha channel margin:

- Old Wadi Wahiba Beneath Dune Sands
- Old Wadi Wahiba

Wahiba Sand Sea: stratigraphy compared to age dates of the Wahiba Sands.

AFTER RADIES, ET AL, 2004
Geologists typical perspective, first well in an eolian reservoir

If the Wahibas were preserved as an oil reservoir, they might be viewed as a single sandstone . . . and thus a single flow unit with a simple history.
Different levels of the dune field were deposited at different times, under very different conditions. Useful reservoir analogues exist at these different levels.
Cross Section Gibbs to Little Mitchell Creek

Build-and-fill controls oil fields, Minnelusa Formation

Gibbs B Sand Oil Field

T 52N

Little Mitchell Creek B Sand Oil Field

Cross section next slide

Minnelusa 3D model from wells created in Petrel by Nick Jones
Build-and-fill of geomorphic accommodation space, Minnelusa Formation

Preserved geomorphic relief on the B sand has trapped oil at Gibbs and L. Mitchell Creek

Minnelusa 3D model from wells created in Petrel by Nick Jones
Cross Section West Gibbs to Bracken

Build-and-fill controls Upper B sand oil fields, Minnelusa Formation

West Gibbs Upper B Sand Oil Field

Bracken Upper B Sand Oil Field

Minnelusa 3D model from wells created in Petrel by Nick Jones
Build-and-fill of geomorphic accommodation space, Minnelusa Formation

Preserved geomorphic relief on the B sand created space for Upper B Sands

Minnelusa 3D model from wells created in Petrel by Nick Jones

Bracken Upper B Sand Oil Field

West Gibbs Upper B Sand Oil Field

Thick B Sand

Thick C Sand

Thick

Thin

Cell height
Wahiba Sands – Build-and-fill eolian reservoir/flow unit creation

- Inherited linear dunes = **BAD ROCK**
- Infill by younger barchans = **GOOD ROCK**

Linear Megadunes are reworked into barchan dunes that fill earlier-created accommodation space.
eolian geomorphology in a dynamic world:
Dune fields interact with nearby depositional environments, producing complex sediment pedigrees and packages.
Some eolian sedimentary units are thin and permeable. They can intercalate with less permeable deposits.
Effects of floods in Wadi Batha. A, strong currents along western side of Wadi Batha have built the gravel bar in the foreground composed of dolomite, limestone, ophiolite and other darker mineral clasts. Waters have eroded the downwind end of linear megadune, causing collapse of sand into the floodwaters and re-cycling into the fluvial domain. B, ponding of muddy floodwaters in an interdune along the northern margin of the megadunes. C, fluvial bar from earlier flood cut by recent flood, view to NW. D, after waters have receded, mud dries with some light colour due to light clays from Barzamanite outcrops weathered upstream and thin salts. View is across Wadi Batha toward the south-southwest.
Further process examples: re-cycling of eolian sand into fluvial deposits, Wadi Batha, Oman

Wadi Batha following flooding. A, view to the southeast showing flooded channel and mud draped over sandy bottom. B, pools of drying water amid various eolian and fluvial bedforms that have been draped with a thick layer of fresh mud. Small ripple forms are fluvial. Larger forms associated with shrubs may be eolian coppice dunes freshly draped with mud. Sand sheet in background (arrow) has remained clear of the flood.
Effects of floods in Wadi Batha after the water dries. A, eolian processes begin to take over Wadi Batha as dunes and loose sand are deposited over fresh mud cracks. B, Cliff cut by flood fills with windblown sand from the south (right). C, drying has caused some light evaporites and clays to whiten on the surface of the Wadi in the interdune where the waters ponded (see Figure 49B above for overview). Muds drape earlier topography caused by stream erosion during the flood’s maximum flow. (note curving channel in foreground). D, flood-and-dry regime leads to small-scale interbedding of eolian dune and fluvial pebbles.
Fluvial and recycled eolian sediments interbedded in Wadi Batha. A, red eolian sand re-deposited by floodwaters is intercalated with dark fluvial gravels and sands. Note red colour of dune sand in background. B, closer to the dune field, dark gravels form a single layer between beds of fluvially recycled eolian sands with small pebbles and mud clasts.
Fluvial systems will pick up eolian sands, improving texture

Fluvial re-cycling of eolian sand. A, Mid-channel bar comprising fluvially recycled reddish eolian sand with climbing ripple structures, pebbles and slump structures flanked by gravel transported from mountains; mainly dolomitic and ophiolitic grains with some limestones. B, Dark gravels overlie much finer, better-sorted, reddish recycled eolian sand with small pebbles below white dashed line. Gray unit below is primary (non-recycled) eolian strata.
Eolian sand from nearby dunes may be recycled into very clean, “eolian looking” fluvial sandstones

Interbedding of eolian (?) and fluvial sands. A, overview of a trench in the wadi channel not far from the edge of a dune. B, detail of trench showing eolian (?) units (base of trench) overlain by fluvial gravels and recycled eolian sands with pebbles.
The pedigree of a fluvial (or shoreline) sand may include an eolian history.

Miqrat Formation outcrops, Huqf area, Oman

Clean white sheetflood sand

Playa facies, haloturbated

Clean sheetflood sand

Huqf Miqrat outcrops have porous sheetflood sands recycled in part from eolian dunes. These are interbedded with impermeable, or low permeability red beds.
The Cambrian Miqrat sheetflood sands have many rounded, frosted “aeolian” appearing sand grains, and little clay. Nearby outcrops have interbedded eolian dunes. (Huqf area)
Useful References


Schenk, C.J., and Fryberger, S.G., 1988, Early diagenesis of eolian dune and interdune sands at White Sands, New Mexico, Sedimentary Geology 55, 109-120.
