Paleosols at Dune du Pilat Reveal Ancient Landscapes and Wind Velocities

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La Dune du Pilat - Arcachon Bay, 60km SW of Bordeaux (44.59° N, 1.2117° W)

Height: 100m | Volume: 60 million m$^3$ of sand
Introduction: History

Image Source: Wikimedia Commons and www.france-voyage.com
Introduction: Timeline

- “Pilat” appears on maps from early 1700s: “Small Bassin of Pilat”
- But no large dune at the time of Louis XIV
- Corresponded to region south of the present dune
- Mobile, dunes moving eastward
Introduction: Timeline

- 1700s-1800s, sand builds up, forming “Dune de la Grave”
- 1826 and 1922 the coastline fell by more than 500m, vegetation destroyed (Clarke et. al, 1999)
- Dune du pilat grows an additional 20-30m to present size of ~110m

Image Source: http://www.dune-pyla.com
Introduction: Sand Supply

- Westerly winds

Image Source: Google Maps and Frederik J. Simons
Introduction: Sand Supply

- Shifts in shallow basin

Image Source: Google Maps and Frederik J. Simons
Introduction: Sand Supply

- Storm events transport massive amounts of sand

Current Dune Movement

~10 m Eastward (2009-2017)

Image Source: Wikimedia Commons and www.france-voyage.com
Mapping Current Dune Movement


\[ \mu_d = 8.88 \quad \sigma_d = 4.69 \]
Mapping Current Dune Movement

Red: 2009 Dune edge
Green: 2017 Dune edge
Paleosols: Understanding Past Landscapes

Images from Google Earth
Paleosols: Understanding Past Landscapes

Images from Google Earth
Introduction

- Paleosols are evidence for how past formations of the dune responded to the landscapes, climate, etc.
- Future development of the dune can be predicted using this information (Roskin et al., 2013)

Introduction

- Studying paleosols can show the climatic conditions during the paleosols formation such as weathering intensity and vegetative covering (Sheldon and Tabor, 2009)

Hypotheses

- Paleosol undulations drape ancient topography
- Dips of paleosols indicate ancient wind direction - a paleowind!
- Grain size depends on paleowind velocity, within paleosols
- Current movement of Dune should continue Eastward

Will our results agree??

GPR: Paleowind Direction
GPR Function

Survey Direction

Photograph by Victoria Gonzàlez
GPR Function

Survey Direction

CPU unit

RADAR antenna

Photograph by Victoria González
GPR Function

Image: Manataki et. Al, 2012
GPR Function

Image: Manataki et. Al, 2012
Velocity = 0.0742 m/ns
Transect Parallel to “Frederik”

Images from Google Earth
Transect: Parallel to Paleosol F: “Frederik”

Walking Direction

Surface (Air Wave)

Paleosol (Critically Reflected)

Reflectors
Elevation Correction (parallel transect)

- Surface
- Paleosol
- Reflectors

Walking Direction: NW

Elevation [m]:
- 0.5m change at 15 m position

Position [m]:
- 0-25 m transect length
Perpendicular To Paleosol F: Frederik

Images from Google Earth
Transect Perpendicular to Paleosol F: “Frederik”

Images from Google Earth
Perpendicular Transect to Paleosol F.

Walking Direction

Surface

Paleosol F

Elevation [m]

position [m]
Perpendicular Transect to Paleosol F.

\[ \theta = 3.06^\circ \]
Transect Parallel to Paleosol A: “Adam”

Images from Google Earth
Parallel Transect to Paleosol A. (Adam)

- Surface
- Walking Direction: NW
- Paleosol A.
- Reflectors
Transect #3 with Elevation Correction

Walking Direction

Surface

Paleosol A.

Reflectors
Transect #3 with Elevation Correction

Walking Direction

Surface

Paleosol A.

Reflectors

- Surface
- Paleosol A.
- Reflectors

Elevation [m]

- 57.5
- 57
- 56.5
- 56
- 55.5
- 55
- 54.5

Position [m]

- 0
- 5
- 10
- 15
- 20
- 25

- 0.8m

?
Transect #3 with Elevation Correction

Walking Direction

$\theta = 9.35^\circ$

Surface

Paleosol A.

Reflected
Transect #4: Perpendicular to third Paleosol

Images from Google Earth
Surface Palesol A.

Walking Direction: WNW

Elevation [m]

Position [m]
Surface $\theta = 13.39^\circ$

Paleosol A
WIND

“Stoss” Side (Erosional)

“Lee” Side (Loosely packed)

EAST
Measured slope of paleosol from parallel transect.

Measured slope of paleosol from perpendicular transect.
Measured slope of paleosol from perpendicular transect

Maximum Angle of Dip = 18 degrees

Measured slope of paleosol from parallel transect
GPR Conclusions

- GPR reveals paleosol topography: bumps on the order of \( \sim 1\text{m} \)
- Dip of paleosol “Frederik”: \( \theta = 3^\circ \) ESE
- Dip of paleosol “Adam”: \( \theta = 13^\circ \) ESE with the dip of the surface being \( \theta = 9^\circ \) WNW
  - Estimated max. dip of 18 degrees to NE
  - Lee side of paleodune
  - Wind direction = to NE
- Need to find wind speed!
We will look at the grain size diameters in the paleosols to determine wind speed and paleosol composition.
Sedimentology Approach
Sedimentology Approach

Paleosol cross-section
Sedimentology Approach

Paleosol cross-section

Sample cell
LDPSA Grain-Size Measurement

Fourier Lens

Particles

Large particles scatter at small angles and vice versa

Detector
Sand Sample Collection

- Excavated cross-section of Adam (top left) and Frederik (bottom right).
- Note color differences in the paleosols
Stereo Microscope Images

Surface Sand Sample

Paleosol Sand Sample
Ellipses fitted to individual sand grains
Red lines = ellipse axes
Grain Size Distributions

\[ \mu_A = 288.28 \quad \sigma_A = 111.37 \quad \mu_F = 337.10 \quad \sigma_F = 99.90 \]

\[ p_1 = 1.92e-06 \quad p_2 = 1.05e-18 \quad p_3 = 3.37e-02 \quad p_4 = 1.59e-17 \]

\[ \mu_A < \mu_F \]

P-values from pairwise Kolmogorov-Smirnov tests
Predicted Threshold Erosional Wind Velocity

- Threshold erosional wind velocity dependent on grain diameter and density (Shao & Lu, 2000)

\[ u_{*t} = \sqrt{A_N (\sigma_p g d + \frac{\gamma}{\rho_d})} \]

- \( A_N \approx 0.0123 \)
- \( \gamma \approx 3 \times 10^{-4} \text{kg s}^{-2} \)
- \( \sigma_p = \text{Particle to air density ratio} \)
- \( d = \text{Grain diameter} \)
- \( \rho = \text{Particle density} \)
Comparing Paleosol F. and Paleosol A.

~2 cm thick organic layer

~0.3 cm thick organic layers
SEDS Discussion
Paleosol “Frederik”

- 3500 to 1000 years ago
- Had Pinus Sylvestris present in paleosol
- 2-5 meters in elevation
- Minimum threshold wind velocity: 0.27 m/s

Image: (Barnroff-Nielsen & Willetts, 1991)
Paleosol “Adam”

- 1000 to 500 years ago
- 20-40 meters in elevation
- Minimum threshold wind velocity: 0.29 m/s
Pinus Sylvestris: found in first and second paleosol

Image:
A033 and A039: Frederik (top two)

A035: Adam (right)
Conclusions

- Present dune will continue to grow, moving to East (no vegetation)
- Dune has moved 25m over the course of the last 7 years
- Lower paleosol “Frederik” dips at 3 degrees EWE - marsh environment
- Upper paleosol “Adam” dips at 18 degrees NE - draping dunes
  - Wind direction comes from SW, a little different than today
  - Slight wind velocity increase from Paleosol F to Paleosol A

Quite consistent with this cartoon!

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References

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