Paleosols at Dune du Pilat Reveal Ancient Landscapes and Wind Velocities

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FRS 135: Shifts and Cycles

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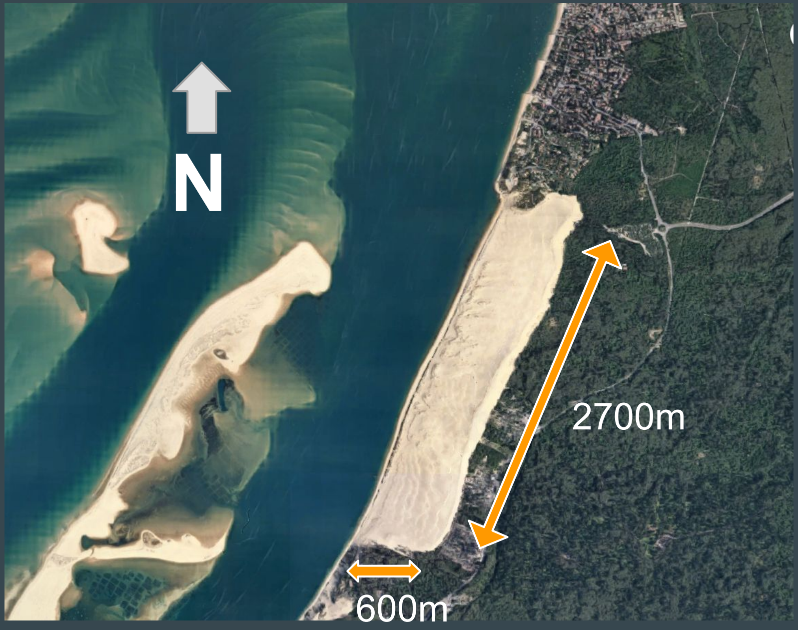
Introduction

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



Images from Google Earth

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

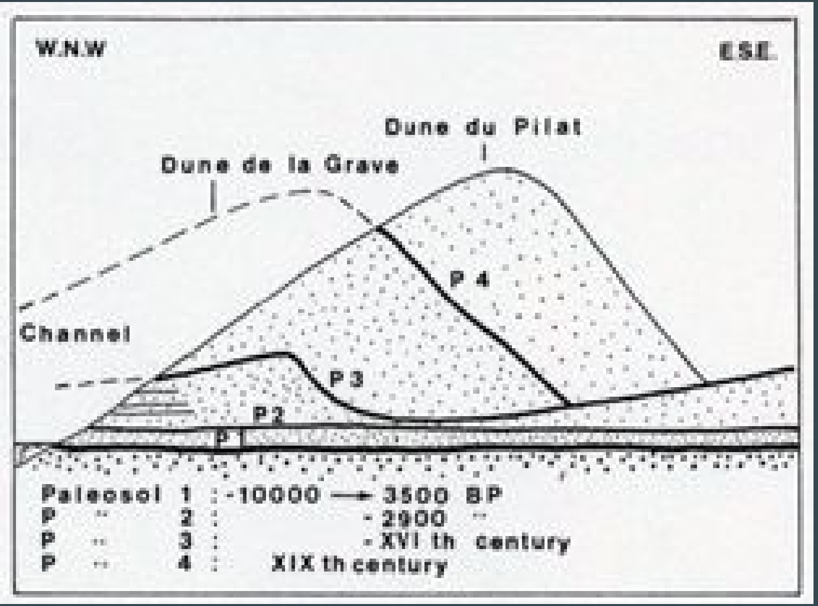


Image Source: http://www.dune-pyla.com

Introduction: Sand Supply

- Westerly winds

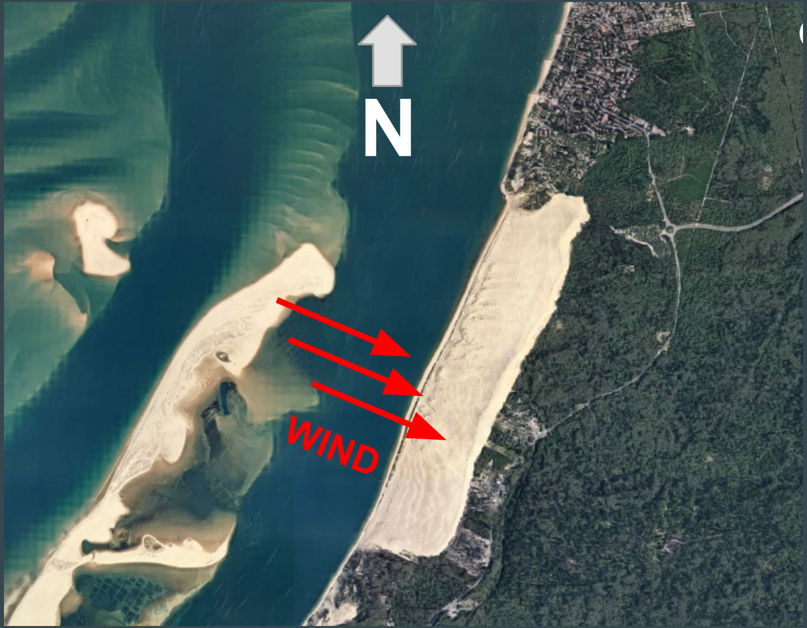


Image Source: Google Maps and Frederik J. Simons

Introduction: Sand Supply

- Shifts in shallow basin

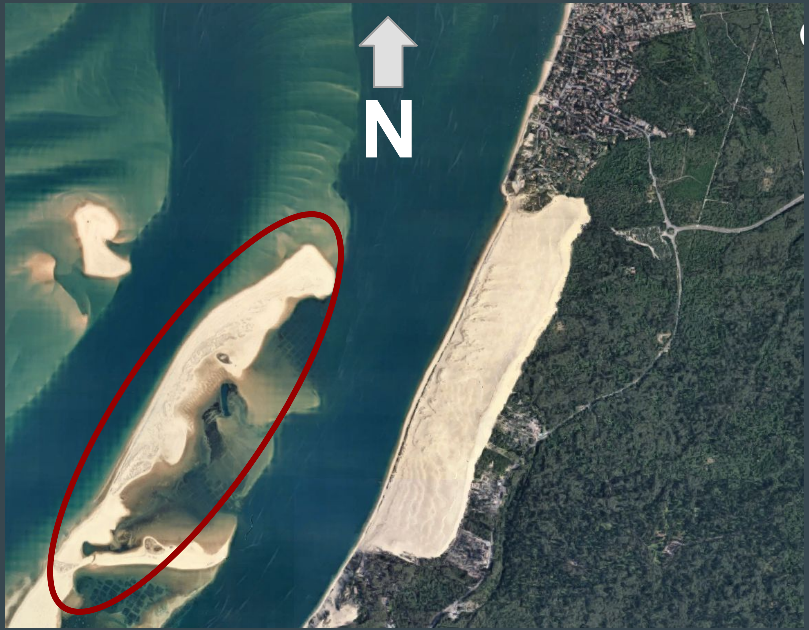


Image Source: Google Maps and Frederik J. Simons

Introduction: Sand Supply

- Storm events transport massive amounts of sand

Image Source: Journal Sud Ouest, http://www.bassin-arcachon-info.com

Current Dune Movement

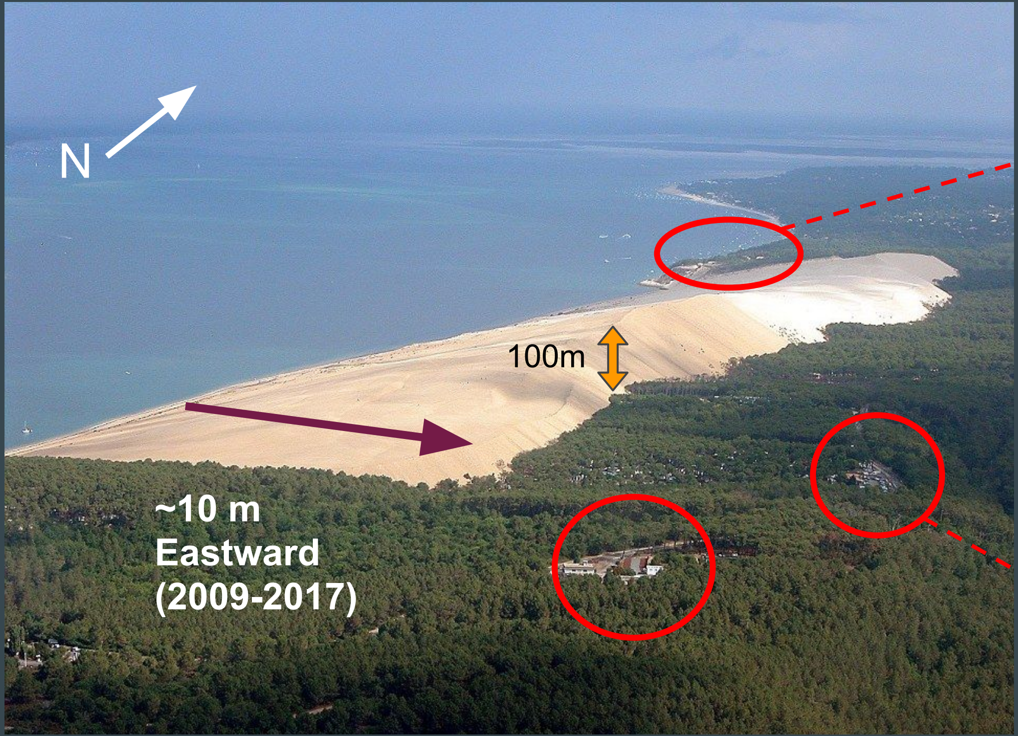
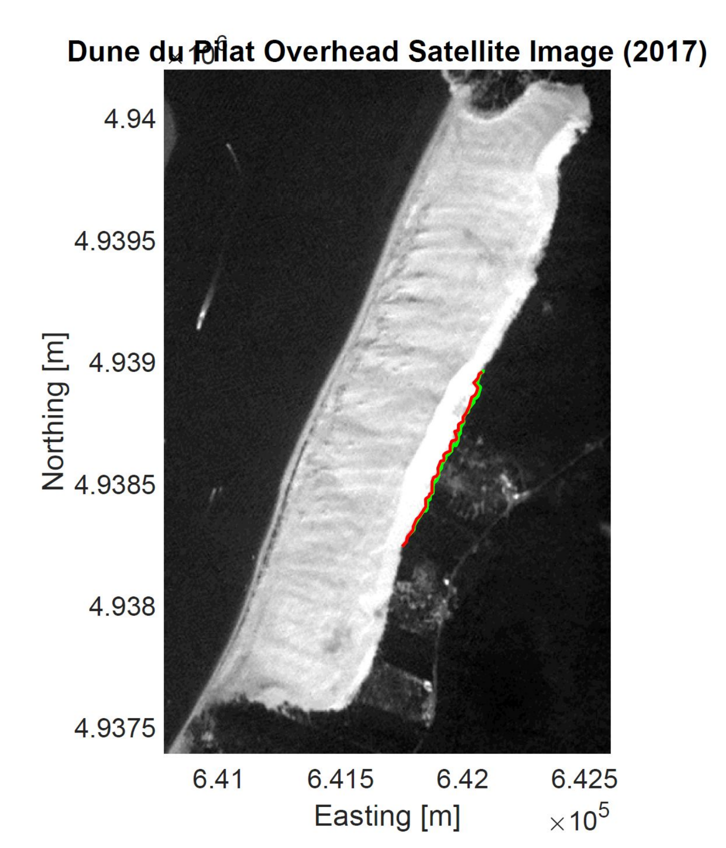
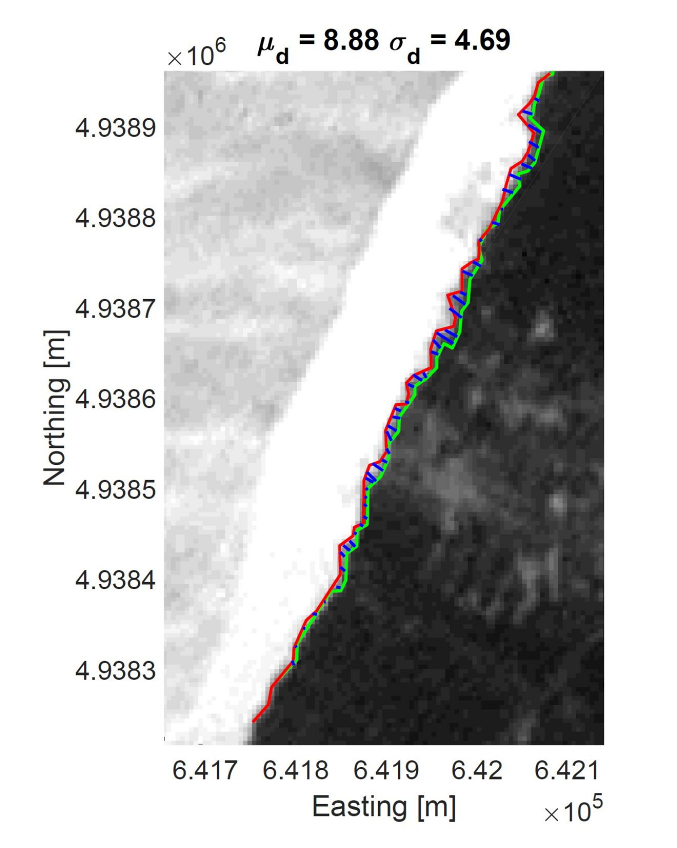


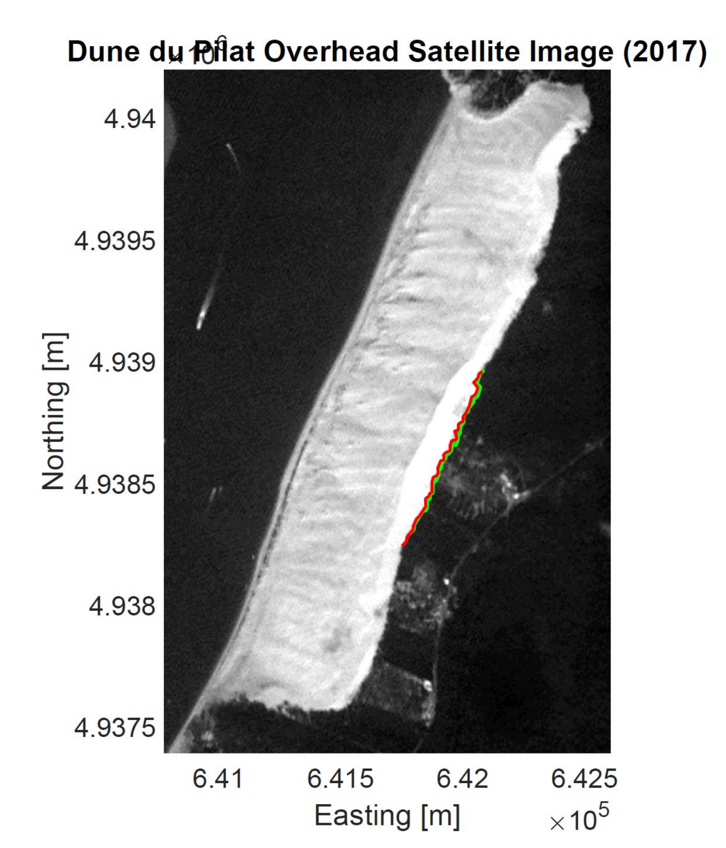
Image Source: Wikimedia Commons and www.france-voyage.com

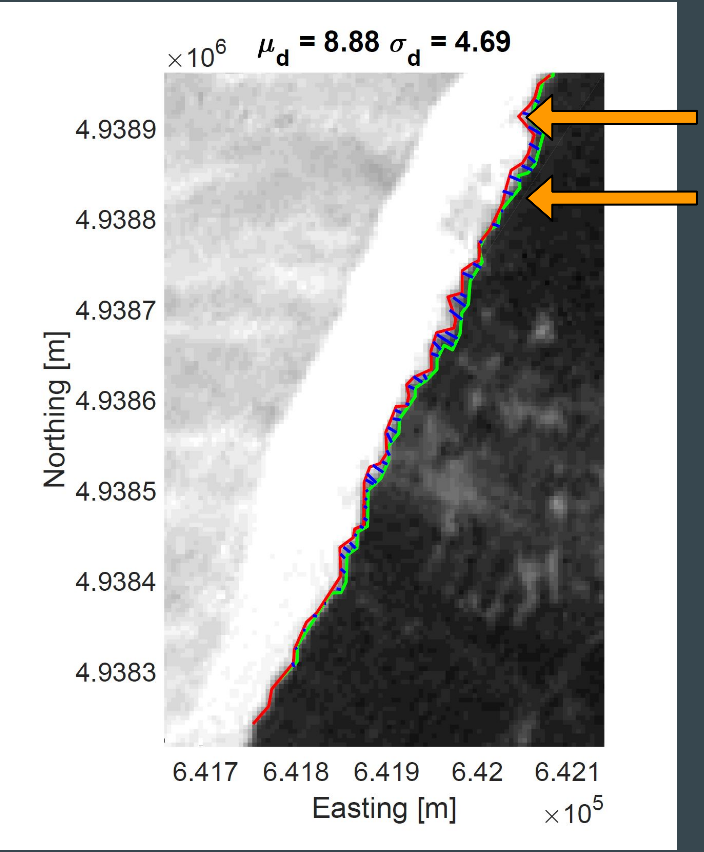
Mapping Current Dune Movement





Mapping Current Dune Movement





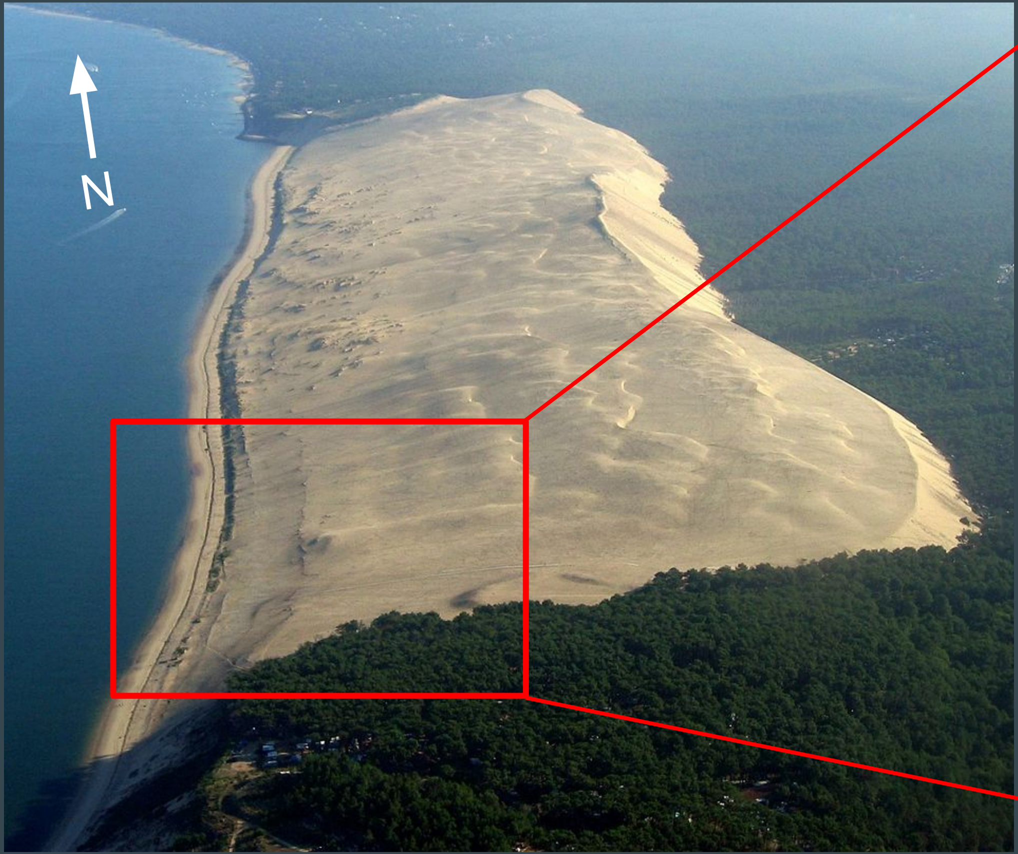
Red: 2009 Dune edge

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)

http://www.dune-pyla.com/en/construction-of-the-great-dune-of-pyla-history.html

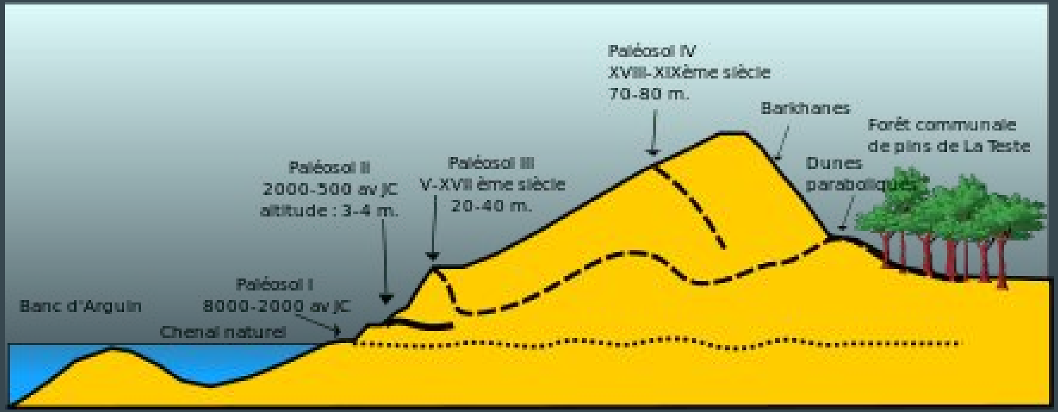
Introduction

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

http://www.dune-pyla.com/en/construction-of-the-great-dune-of-pyla-history.html

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??

http://www.dune-pyla.com/en/construction-of-the-great-dune-of-pyla-history.html

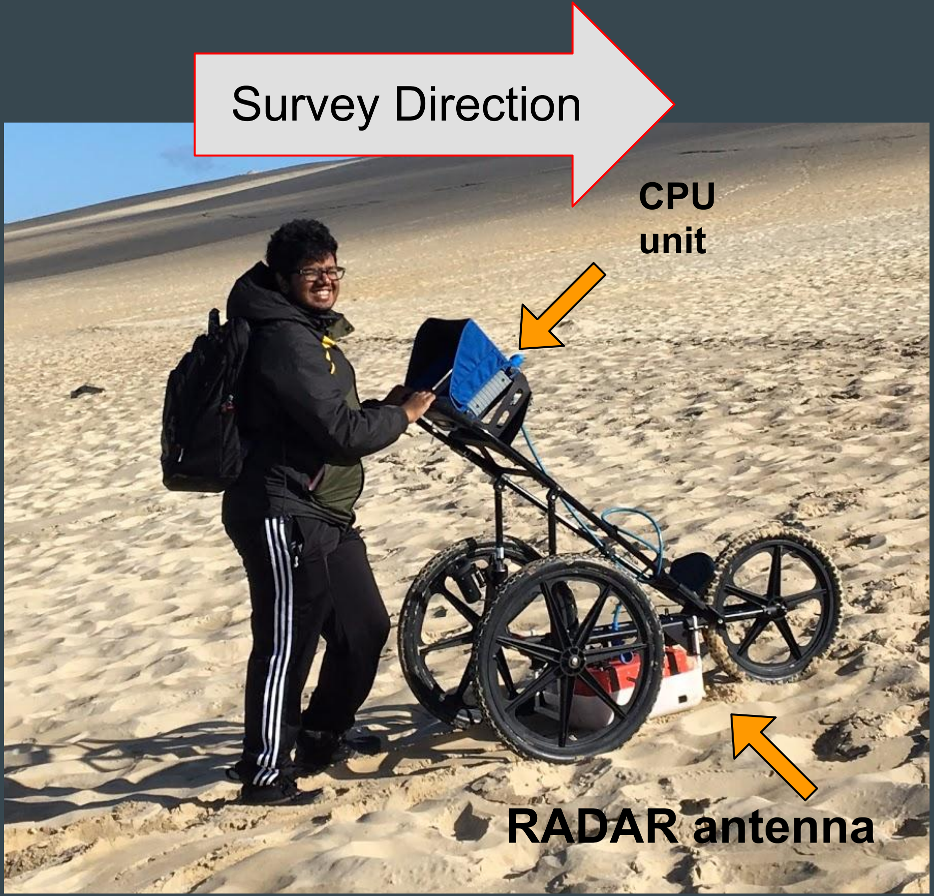
GPR: Paleowind Direction

GPR Function

Survey Direction

Photograph by Victoria Gonzàlez

GPR Function



Photograph by Victoria Gonzàlez

GPR Function

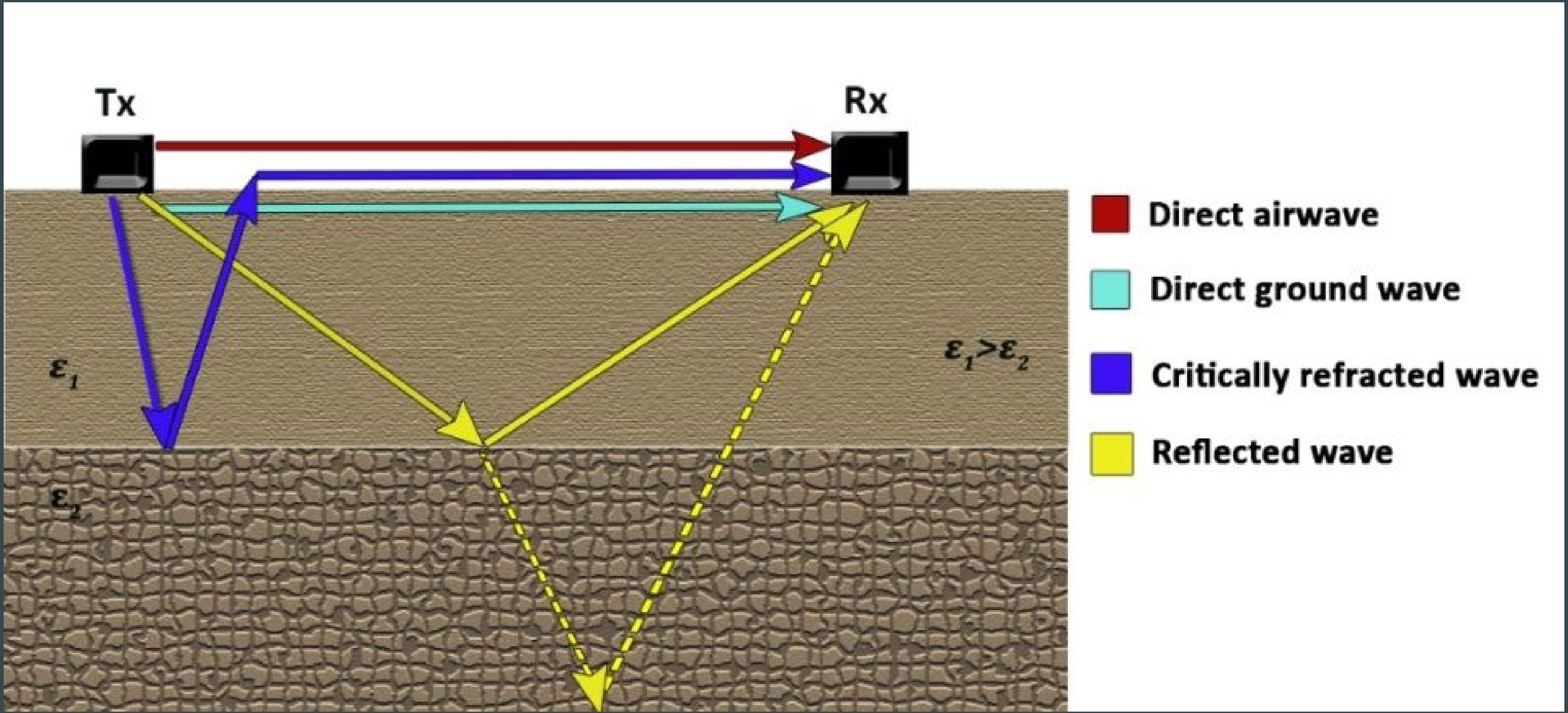


Image: Manataki et. Al, 2012

GPR Function

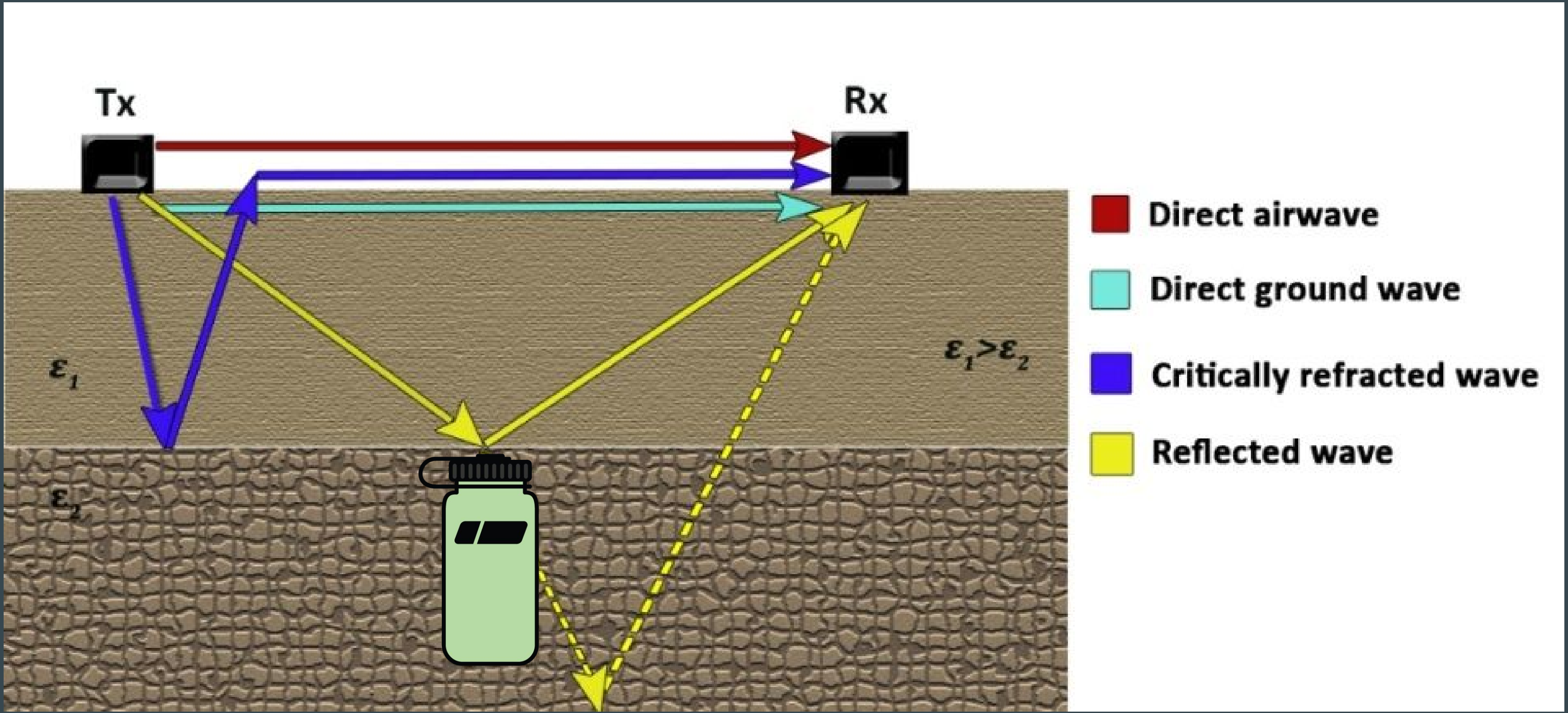
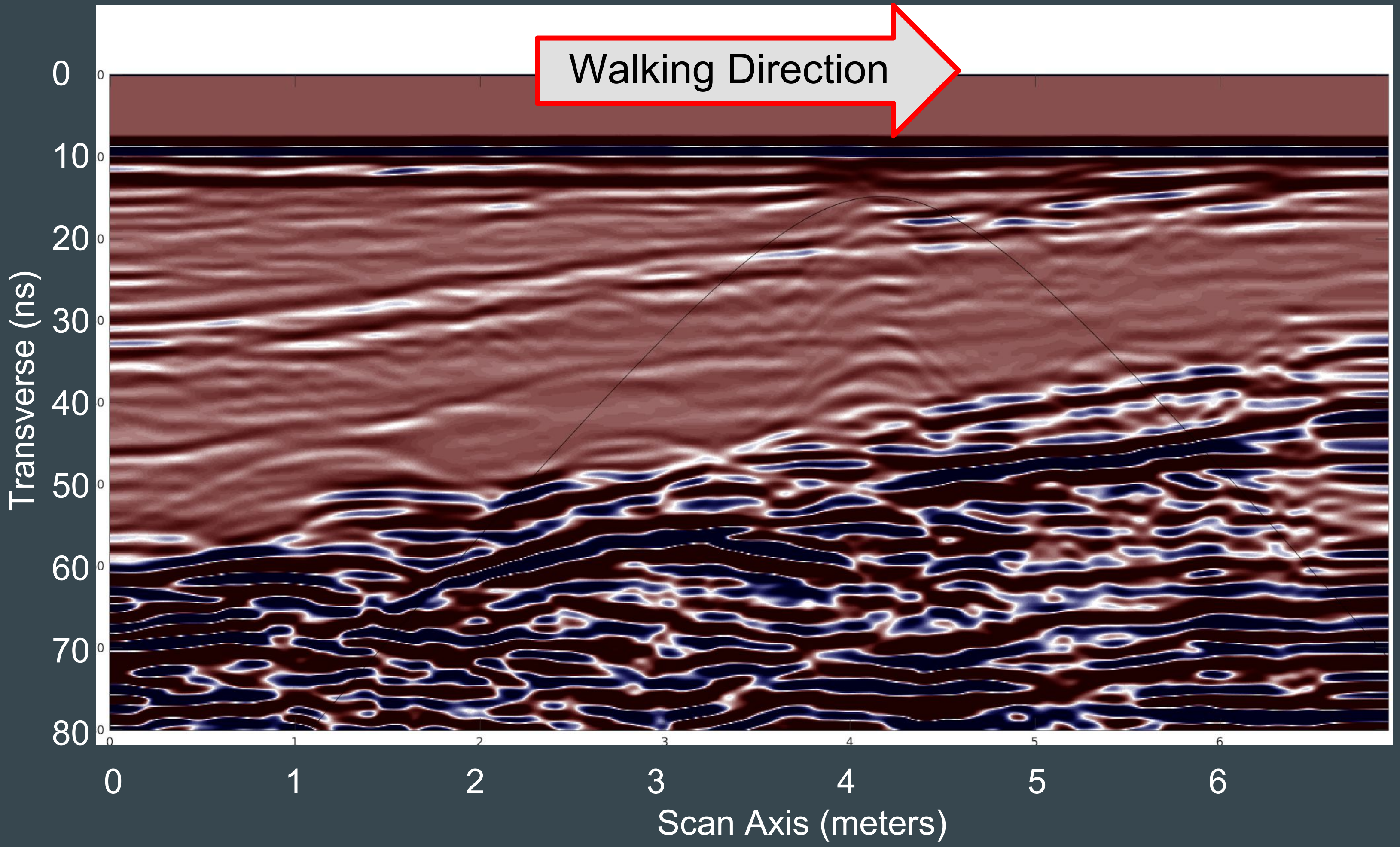
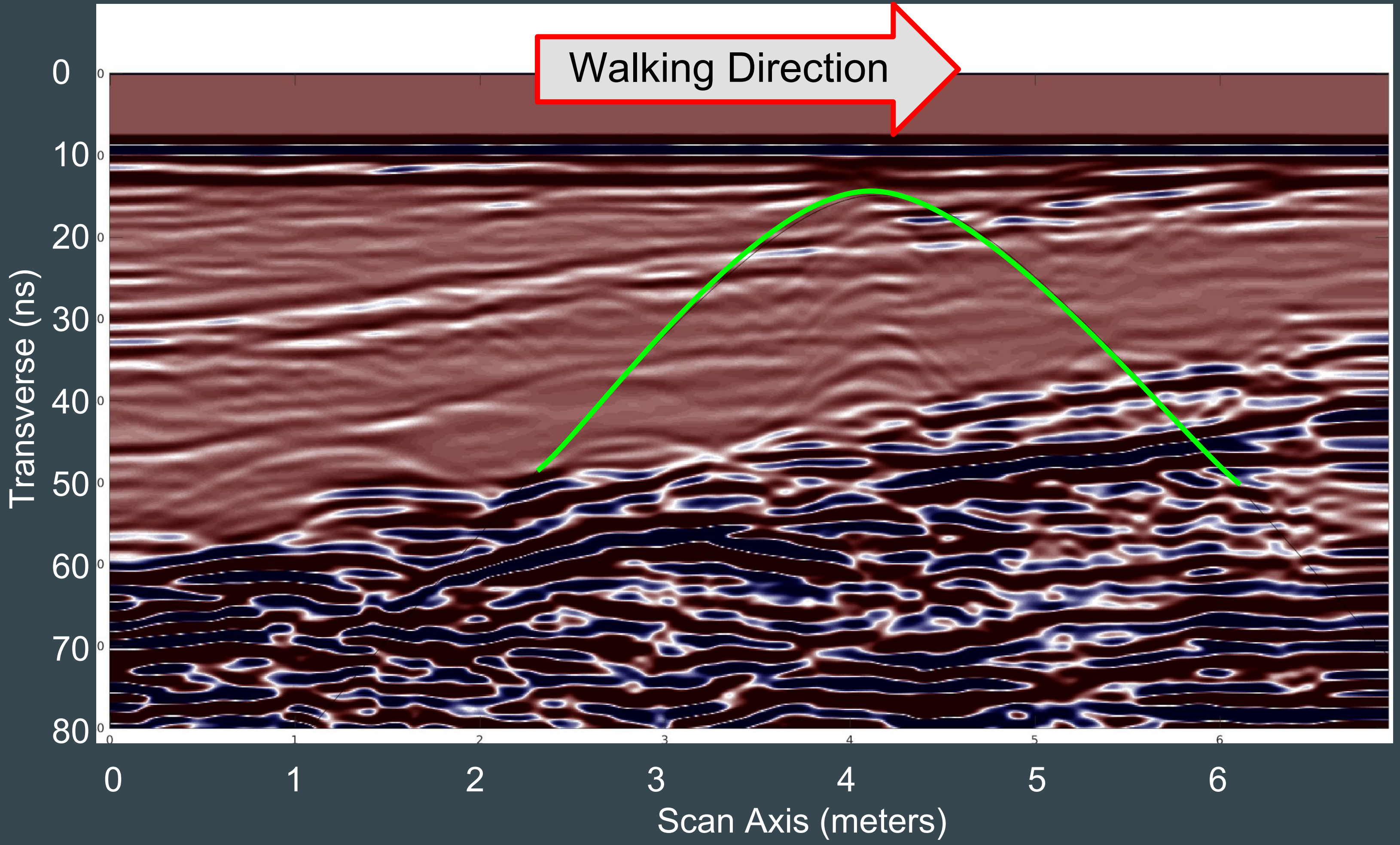
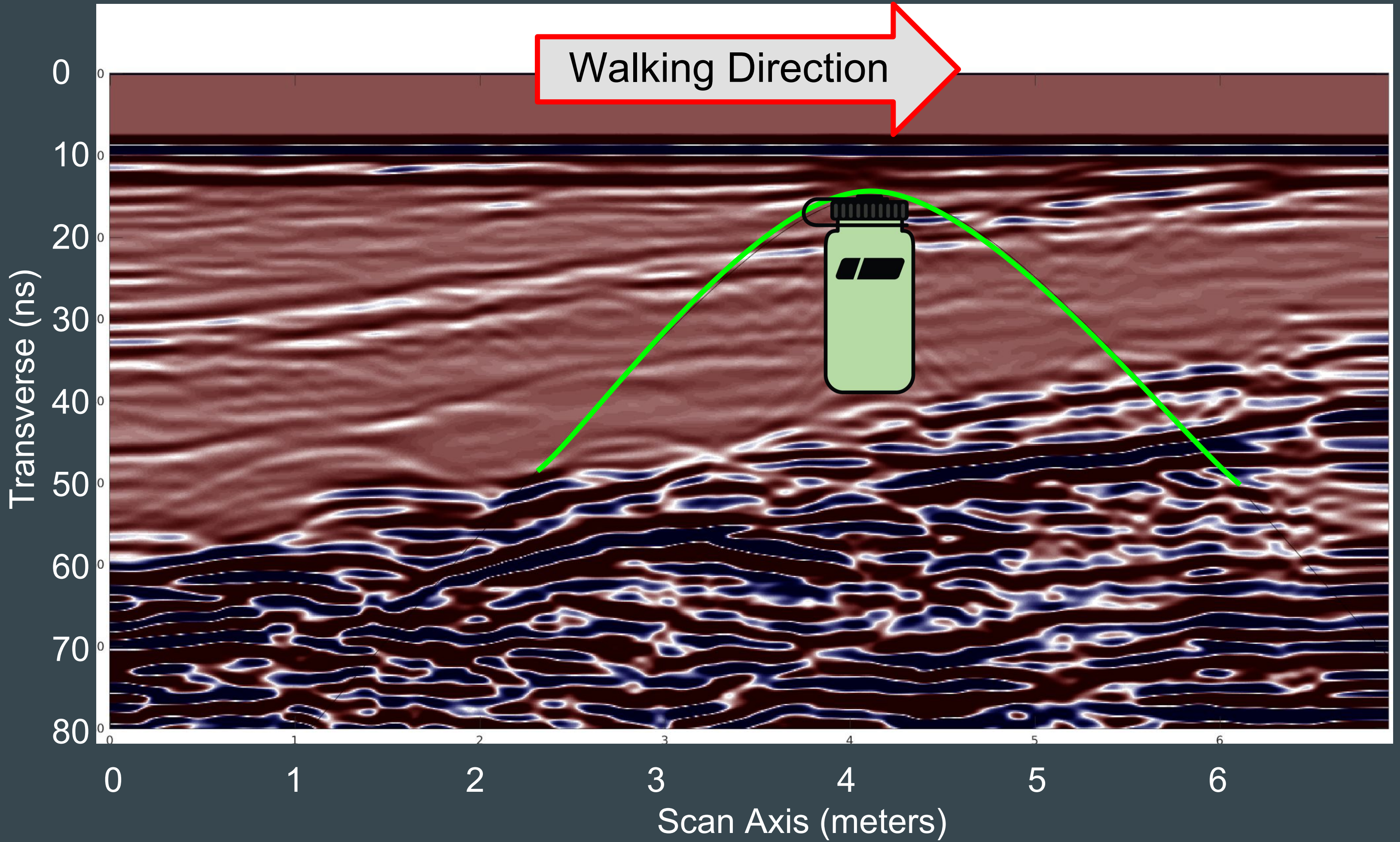


Image: Manataki et. Al, 2012


Walking Direction
Transverse (ns)
0
10
20
30
40
50
60
70
80
0
1
2
3
4
5
6
Scan Axis (meters)


Walking Direction
Transverse (ns)
0
10
20
30
40
50
60
70
80
0
1
2
3
4
5
6
Scan Axis (meters)



Velocity = 0.0742 m/ns

GPR Transects

------------------------------200m----------------------------

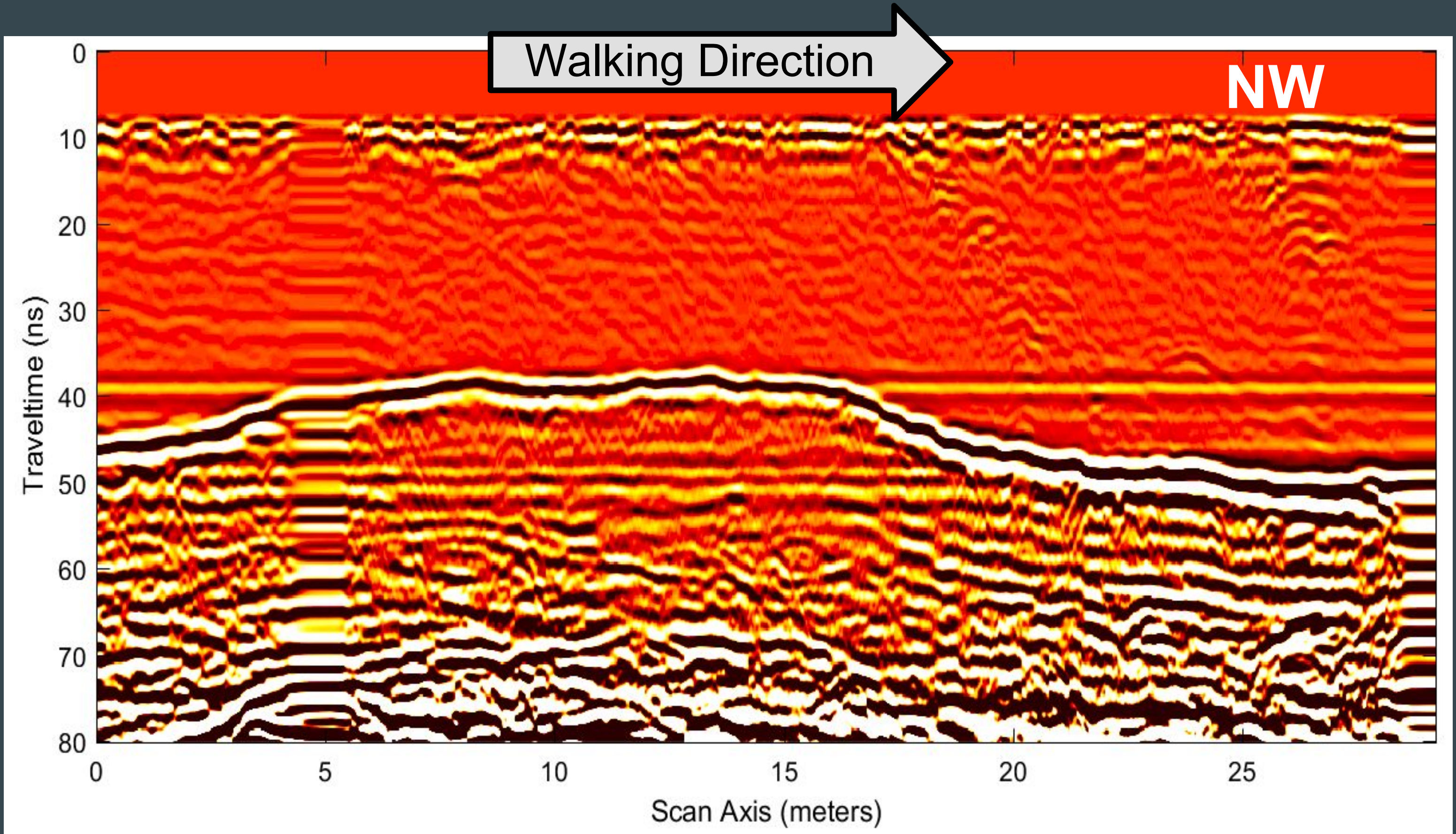
Images from Google Earth

Transect Parallel to “Frederik”

-----------------------------200m----------------------------

Images from Google Earth

Transect: Parallel to Paleosol F: “Frederik”



Surface

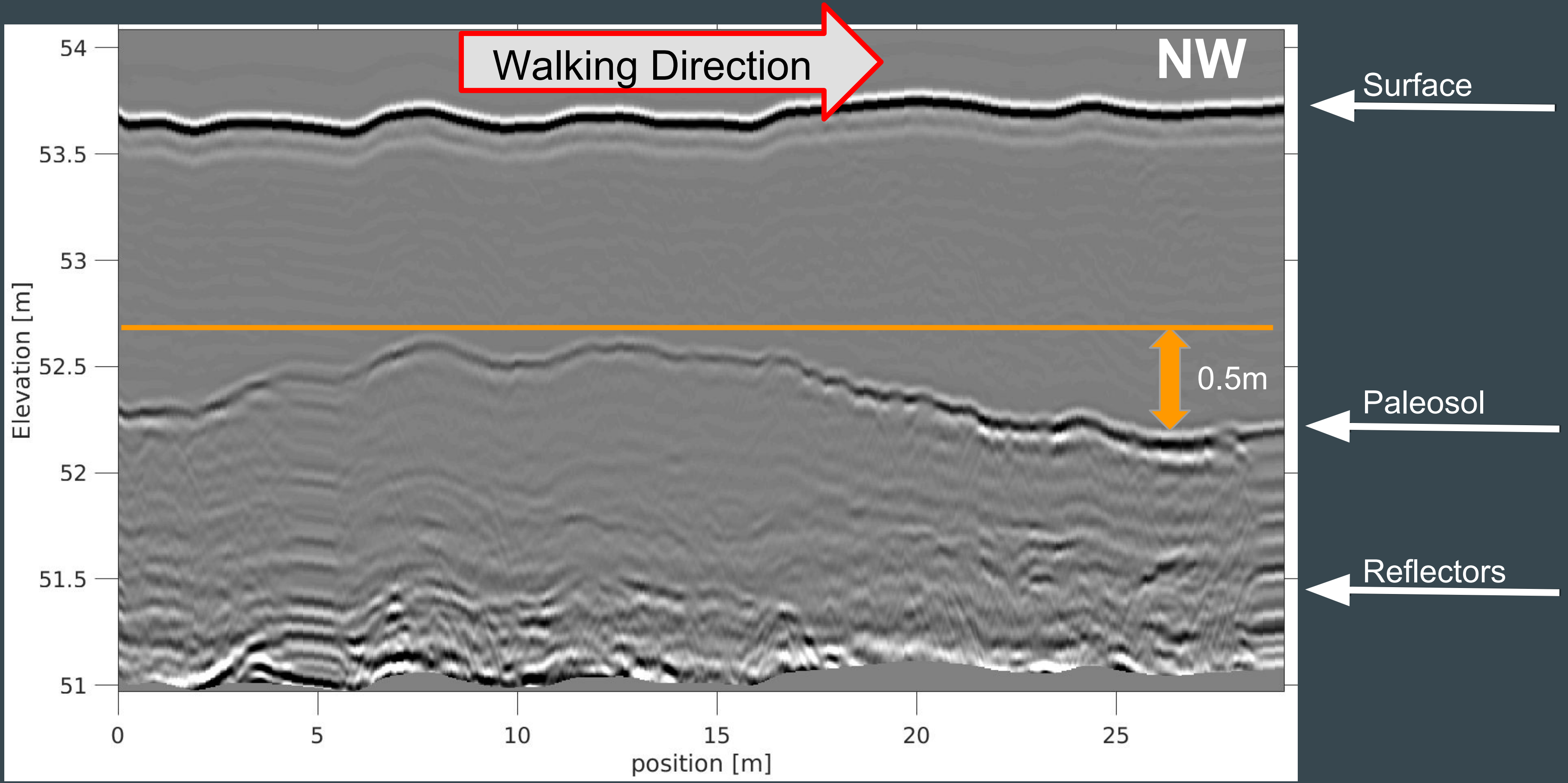
(Air Wave)

Paleosol

(Critically Reflected)

Reflectors

Elevation Correction (parallel transect)

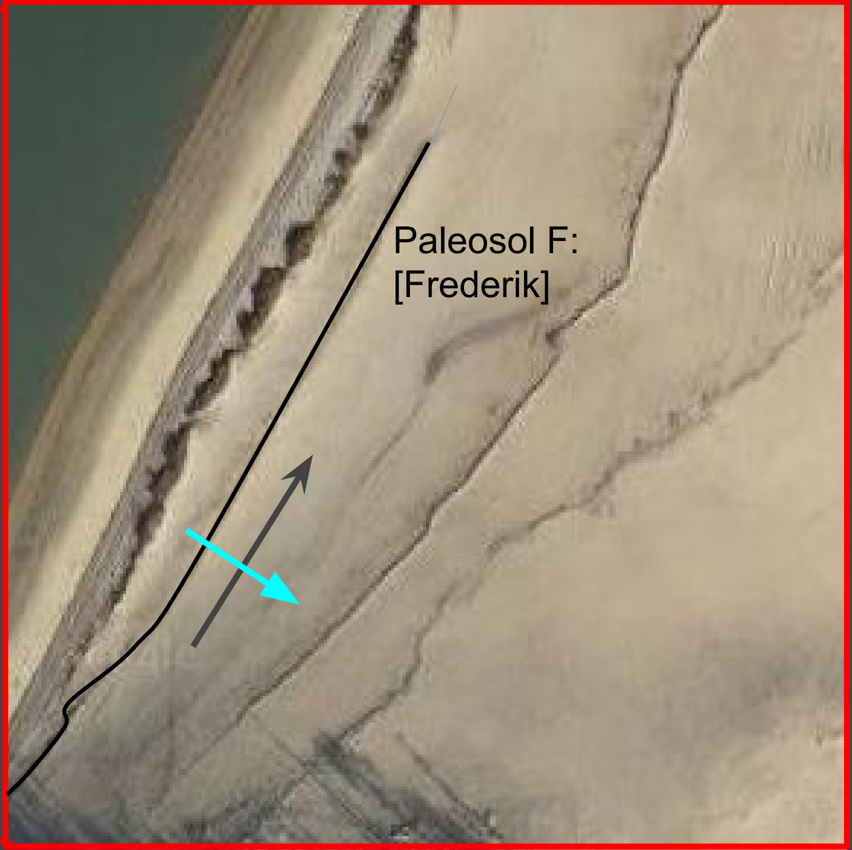


Perpendicular To Paleosol F: Frederik

-----------------------------200m----------------------------

Images from Google Earth

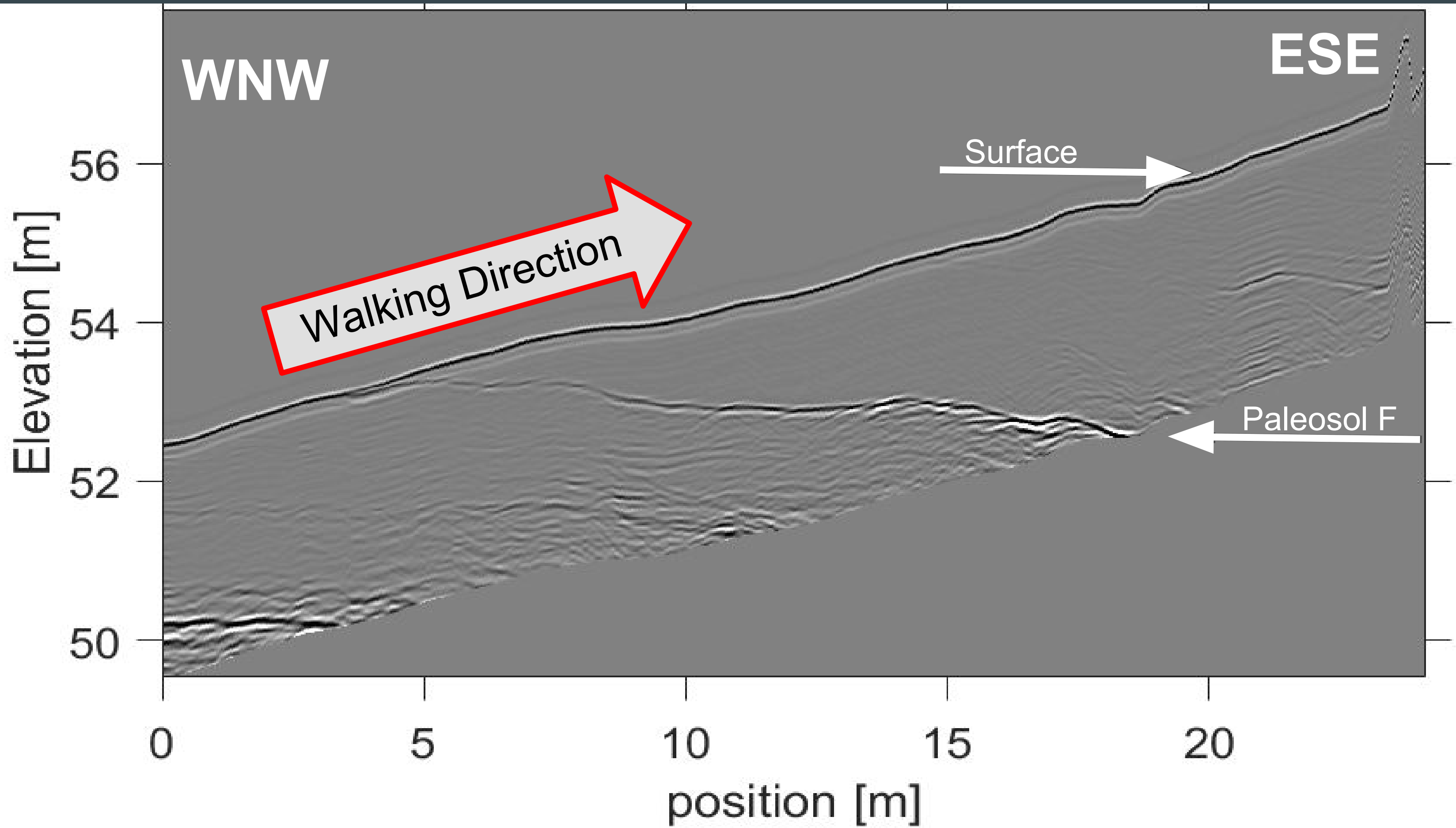
Transect Perpendicular to Paleosol F: “Frederik”



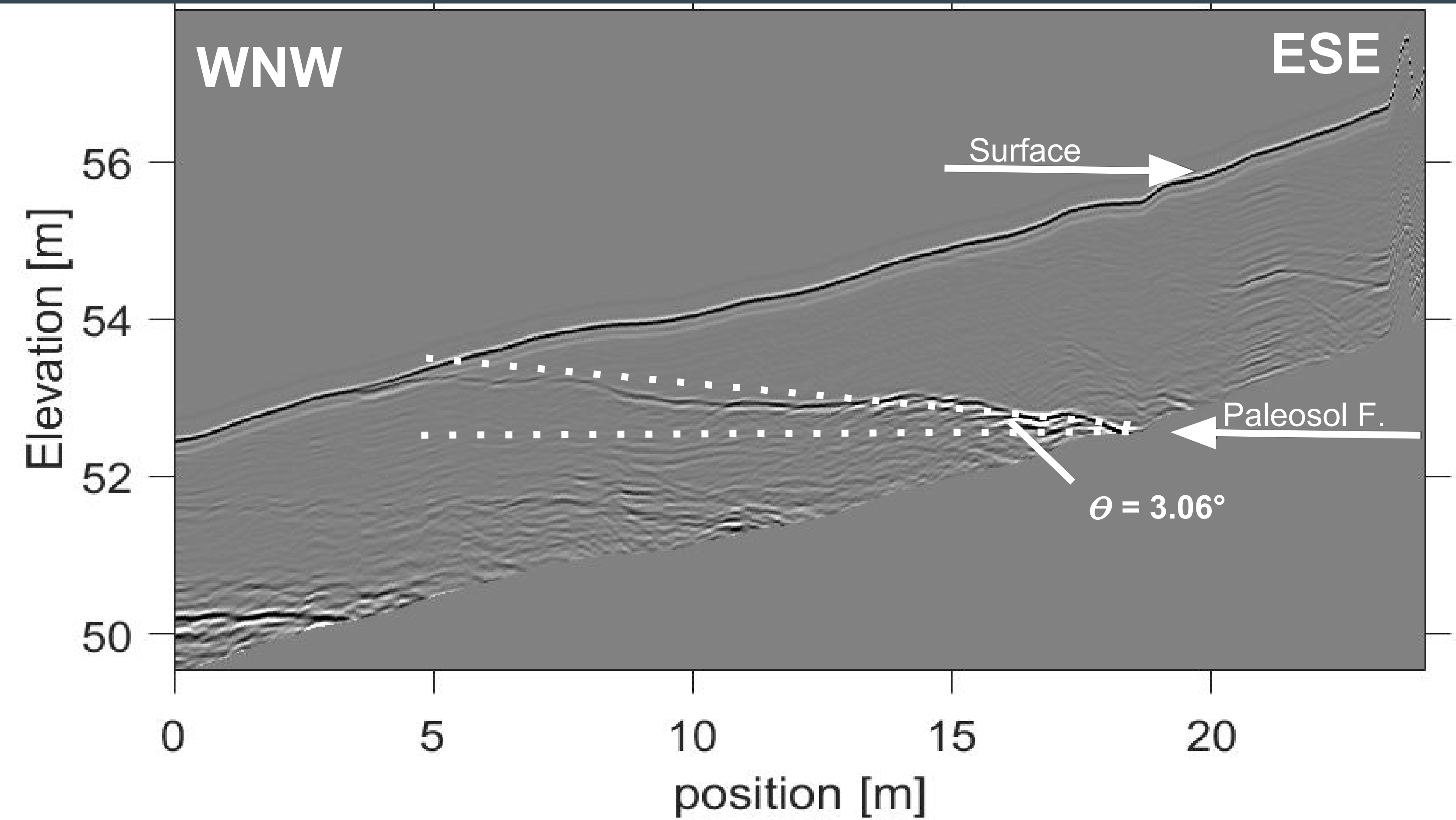
-----------------------------200m-----------------------------

Images from Google Earth

Perpendicular Transect to Paleosol F.



Perpendicular Transect to Paleosol F.

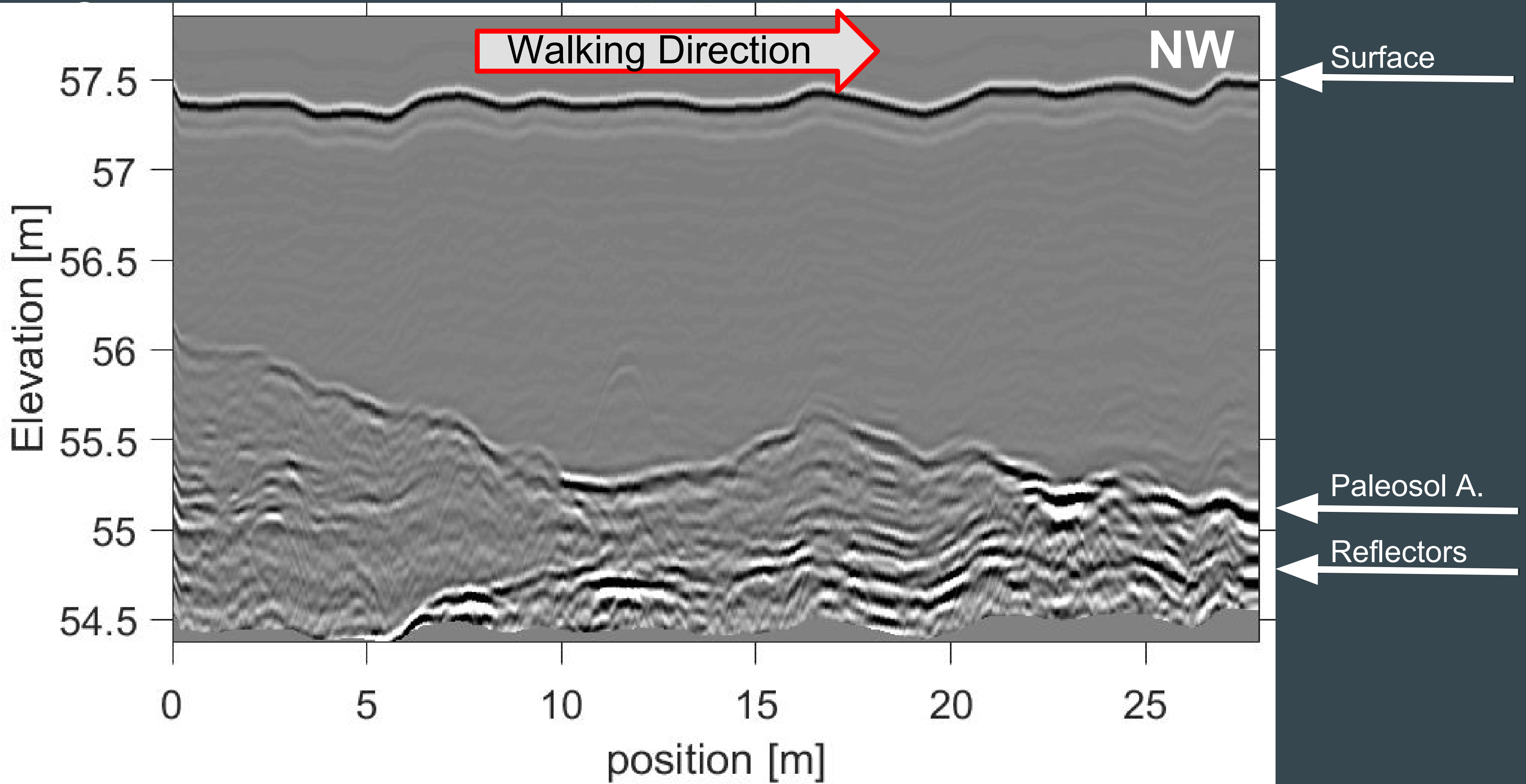


Transect Parallel to Paleosol A: “Adam”

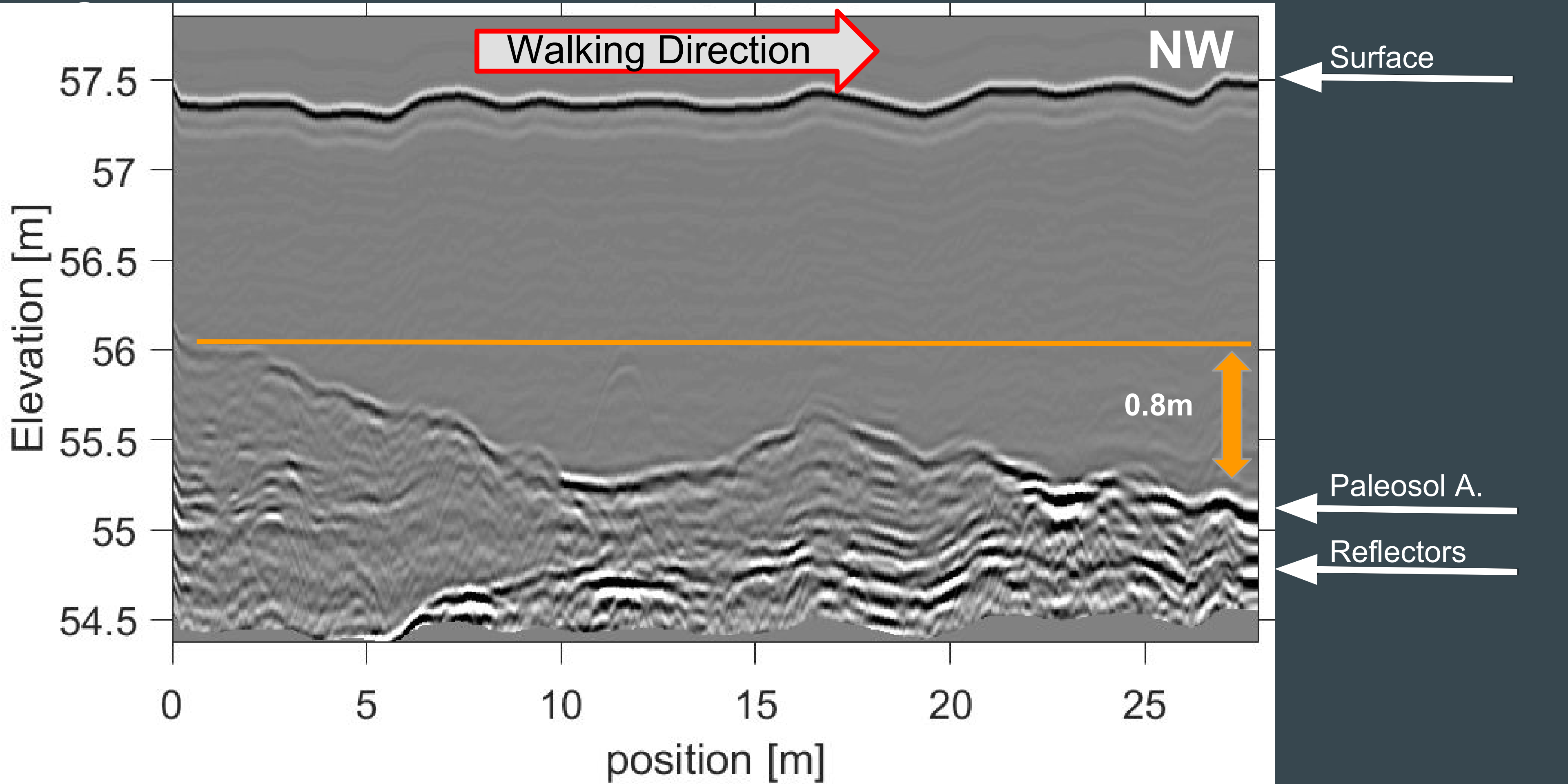
-----------------------------200m----------------------------

Images from Google Earth

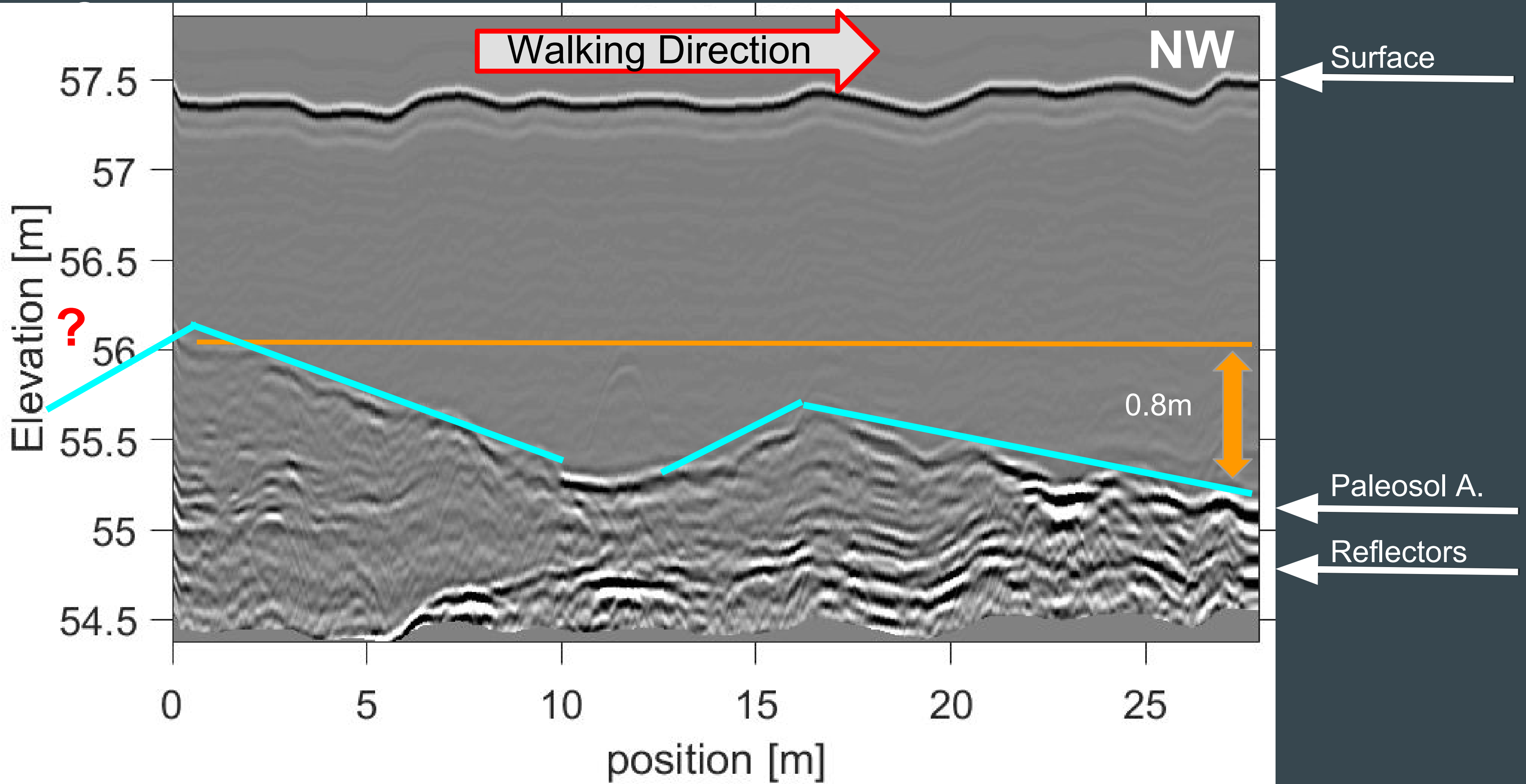
Parallel Transect to Paleosol A. (Adam)



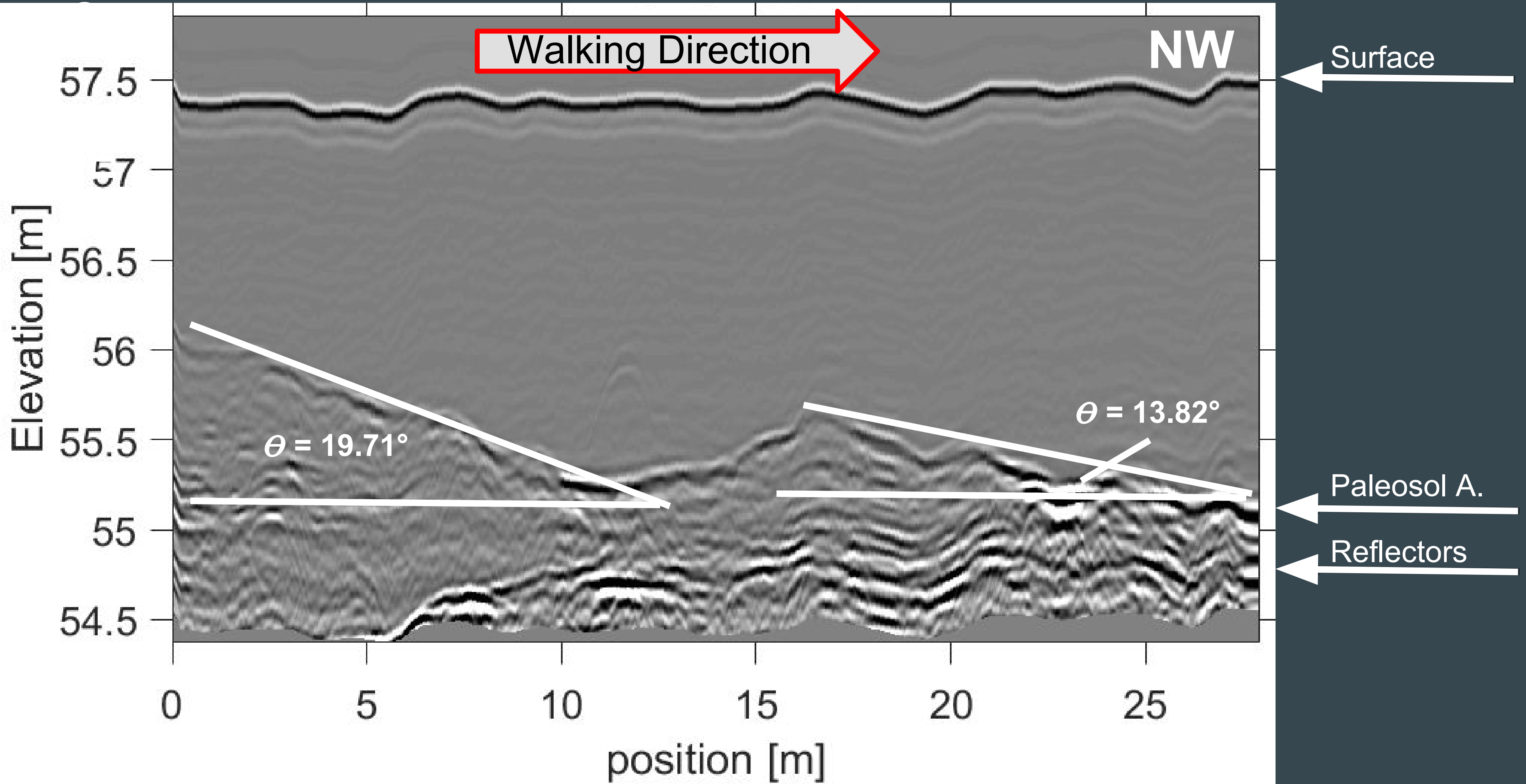
Transect #3 with Elevation Correction



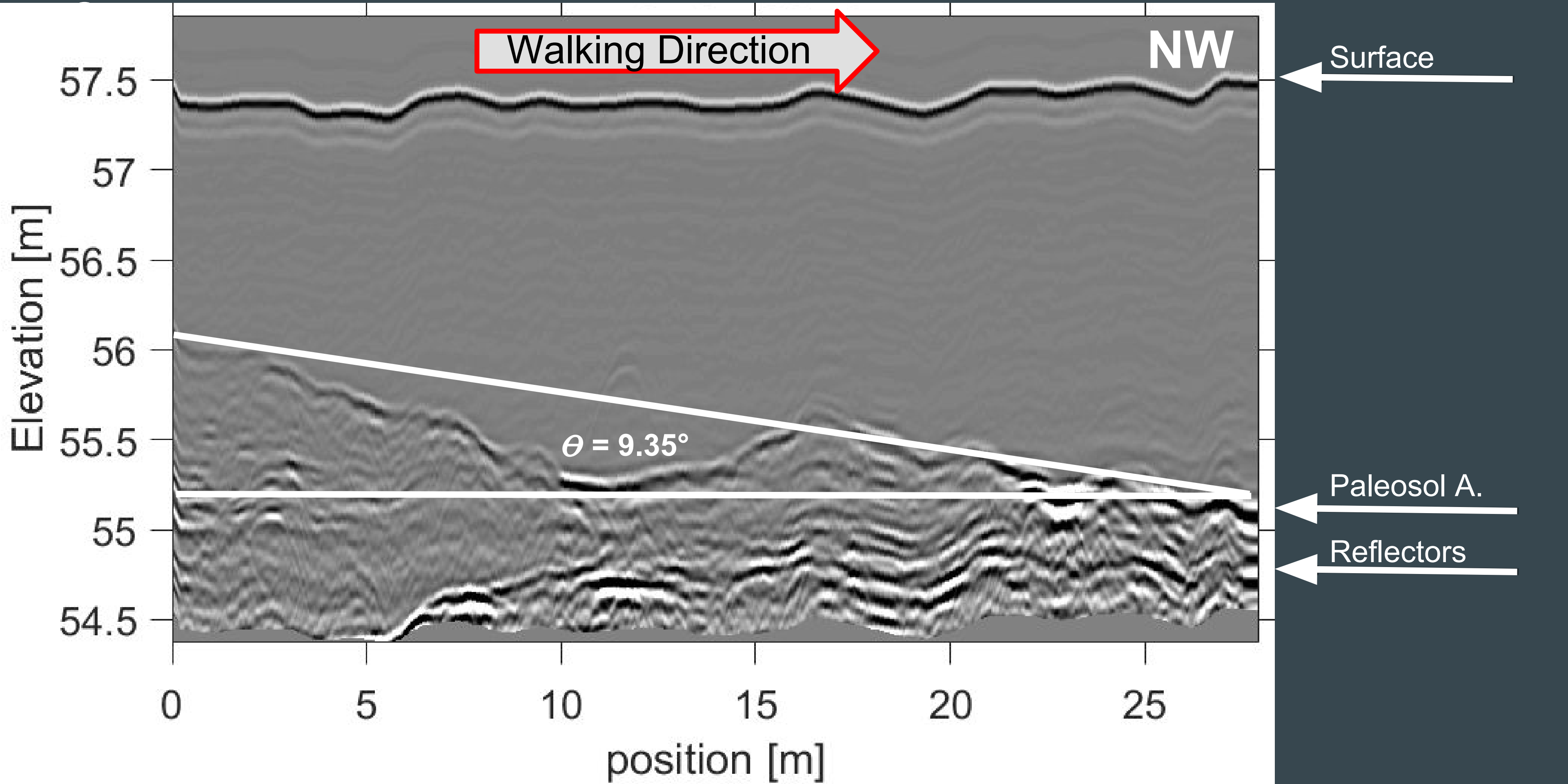
Transect #3 with Elevation Correction



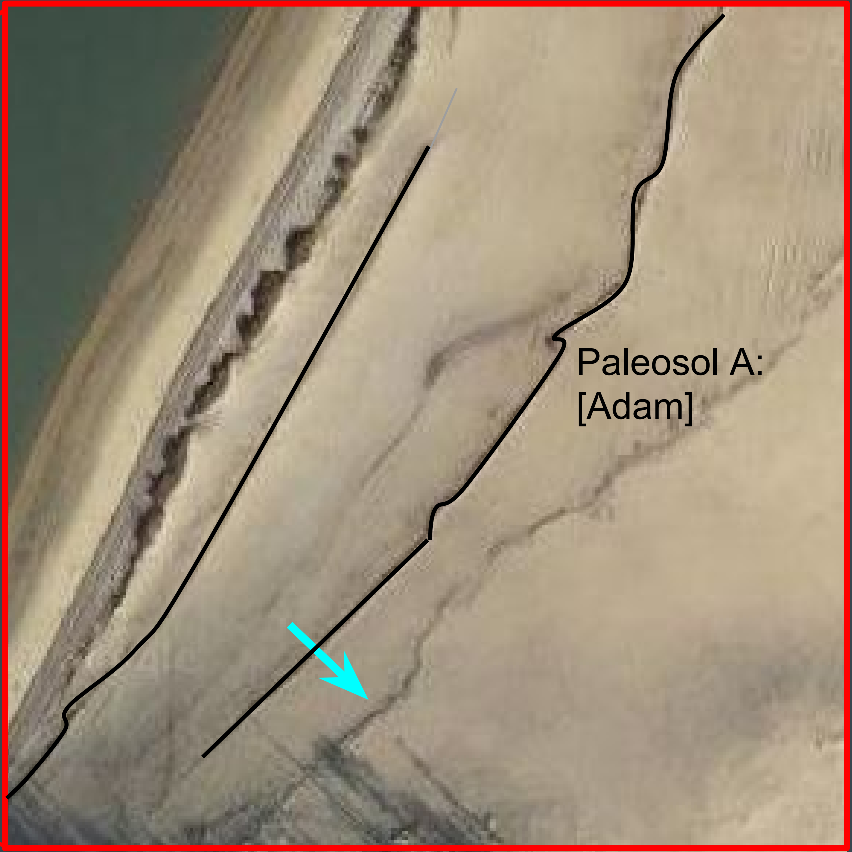
Transect #3 with Elevation Correction



Transect #3 with Elevation Correction

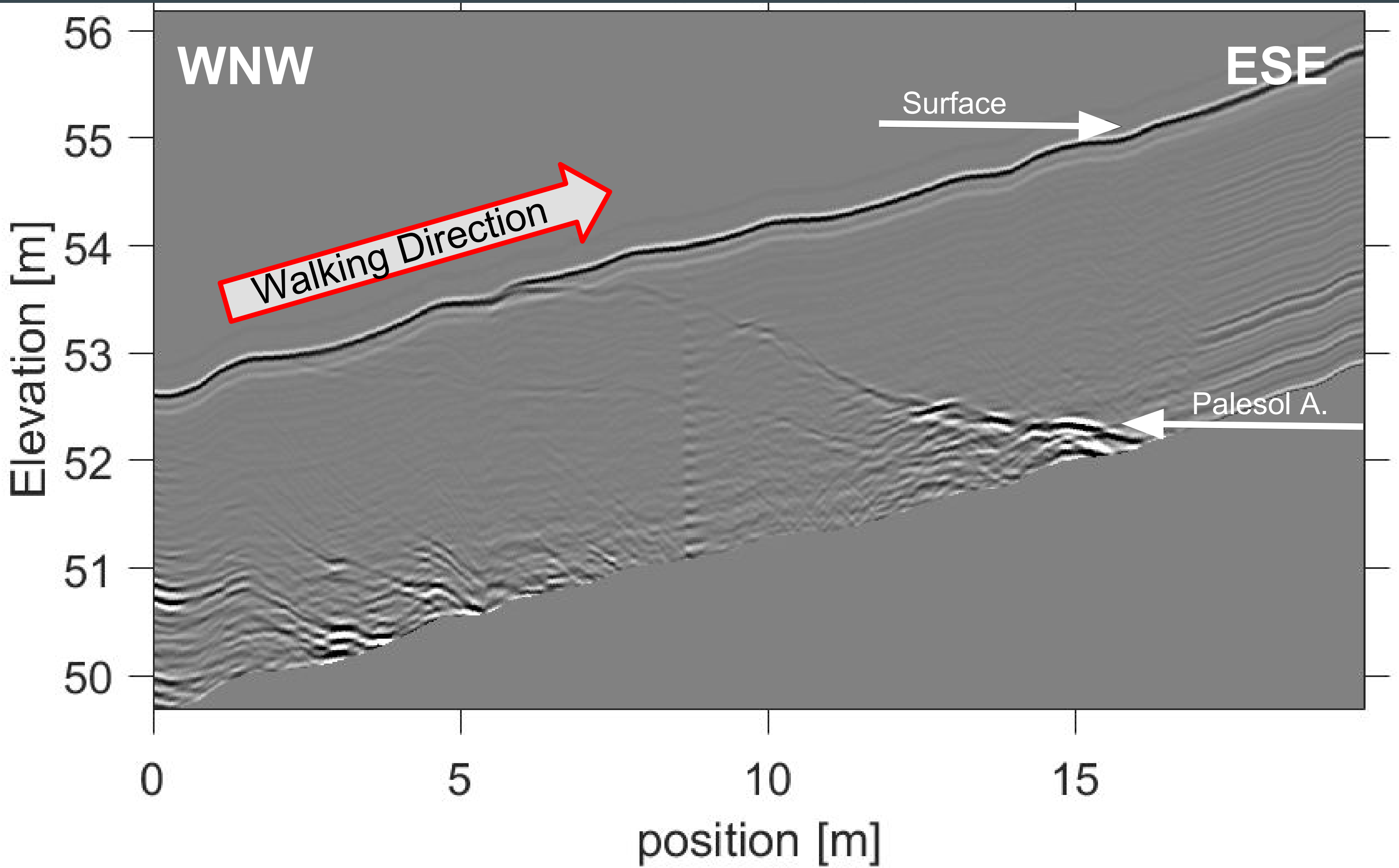


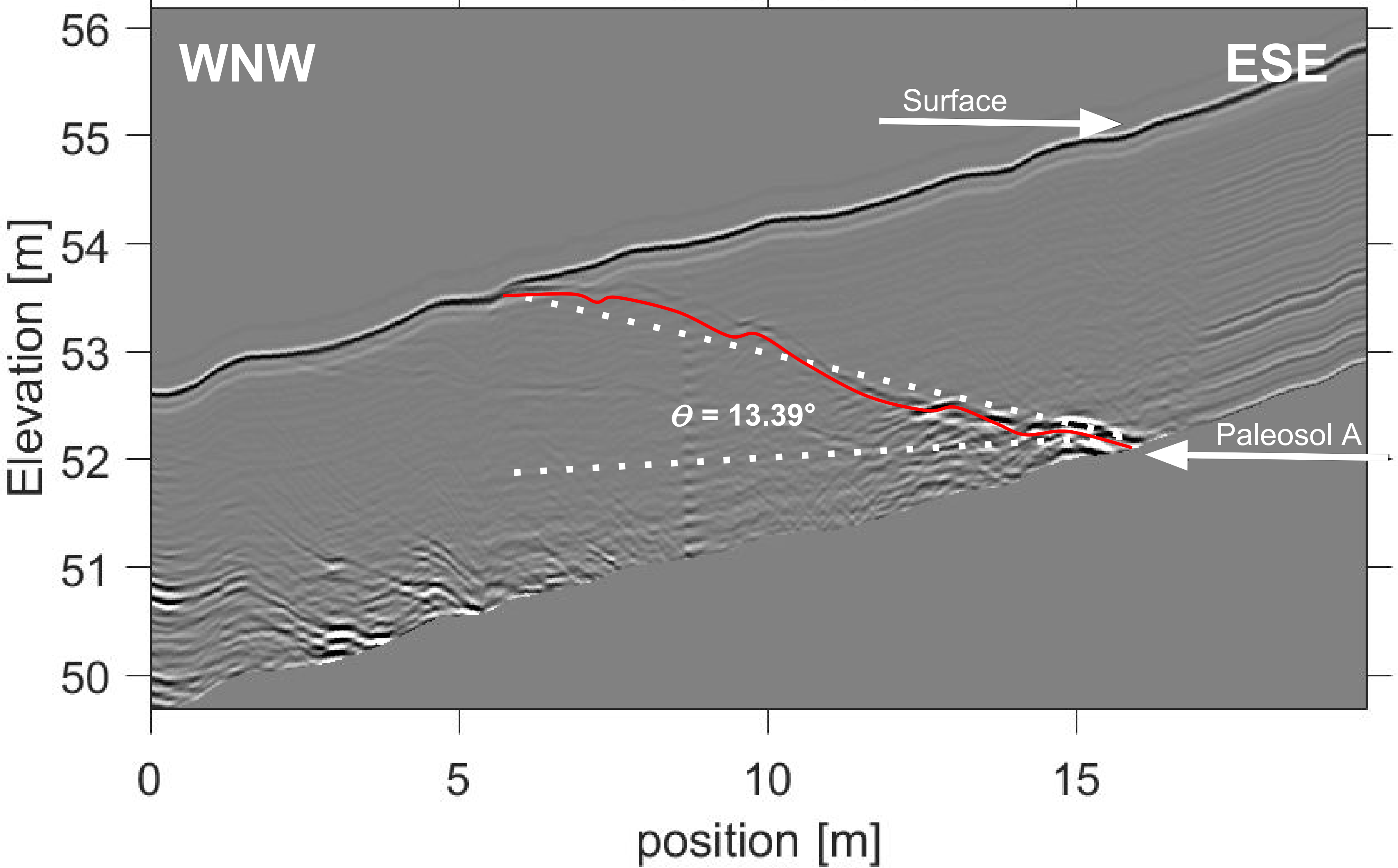
Transect #4: Perpendicular to third Paleosol

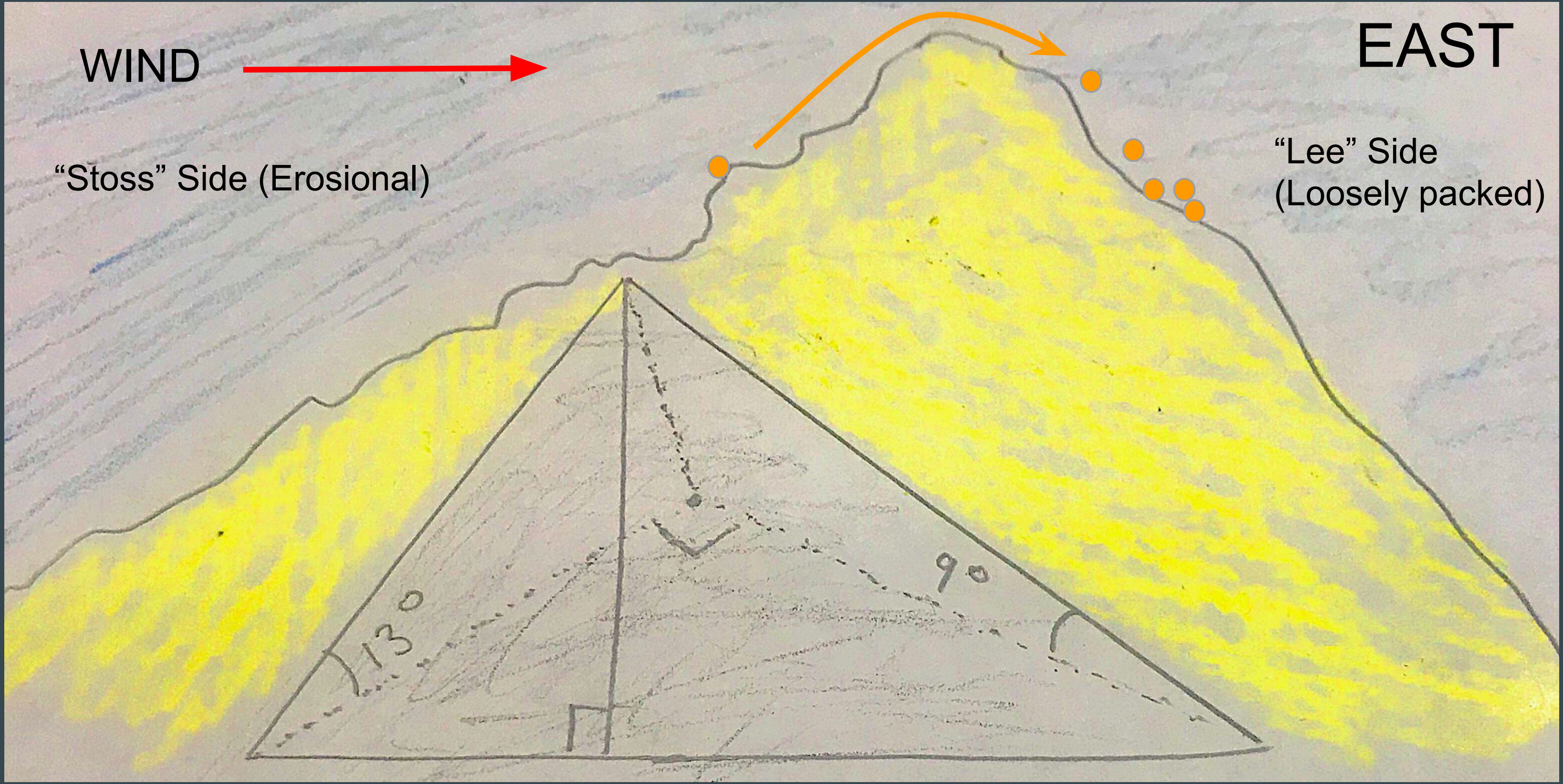


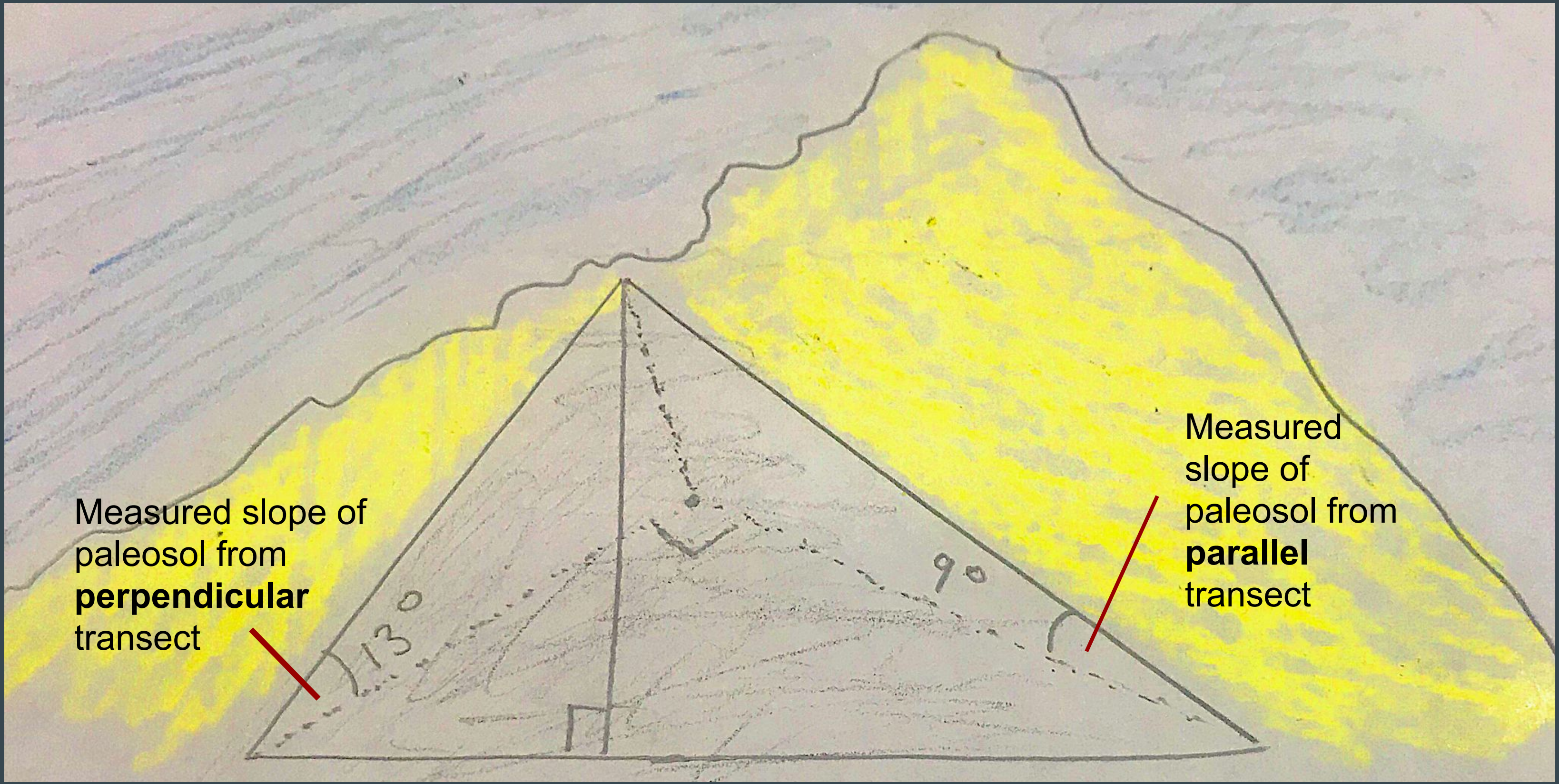
-----------------------------200m----------------------------

Images from Google Earth

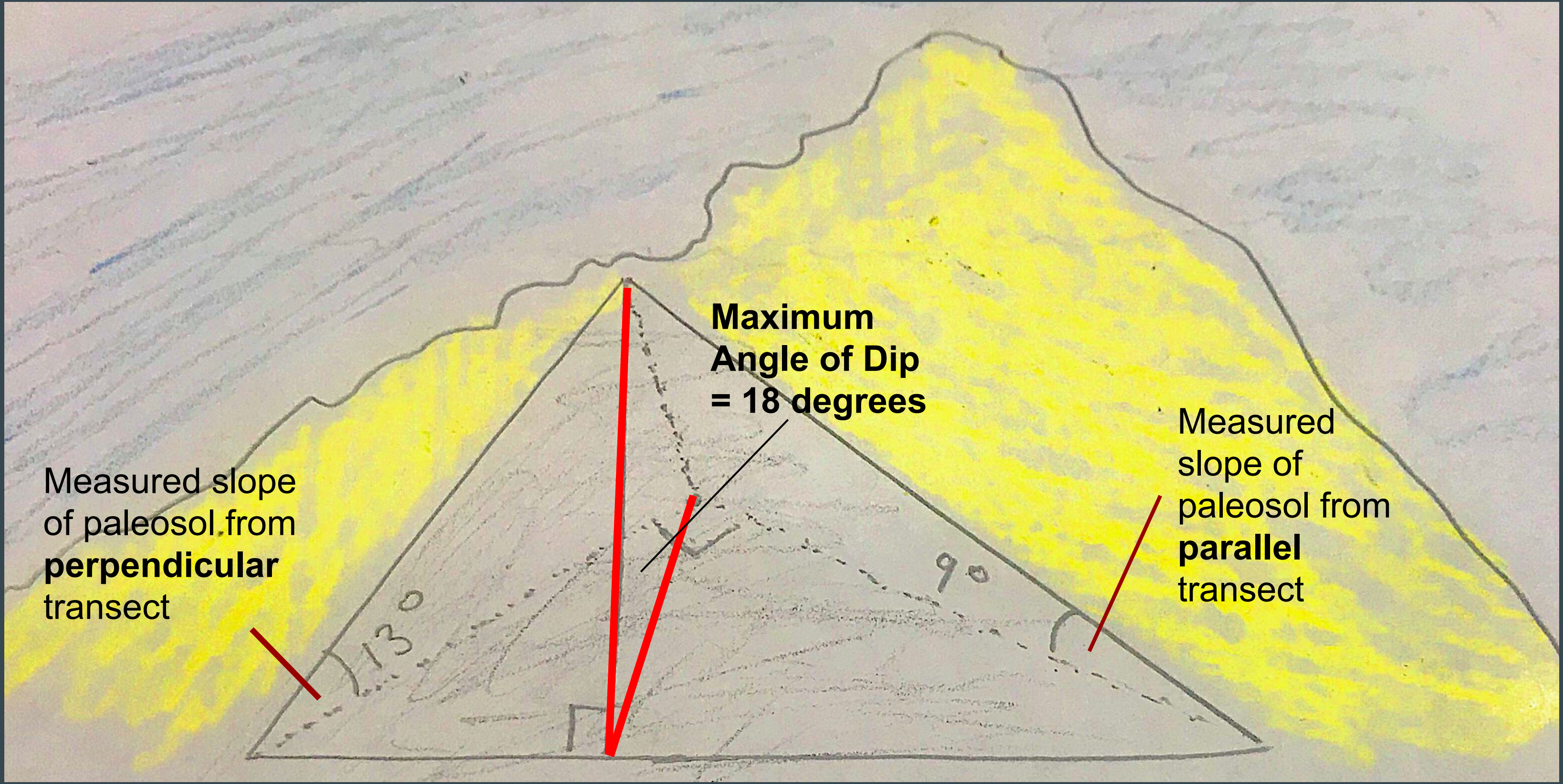

WNW
ESE
Surface
Walking Direction
Palesol A.
Elevation [m]
56
55
54
53
52
51
50
0
5
10
15
position [m]

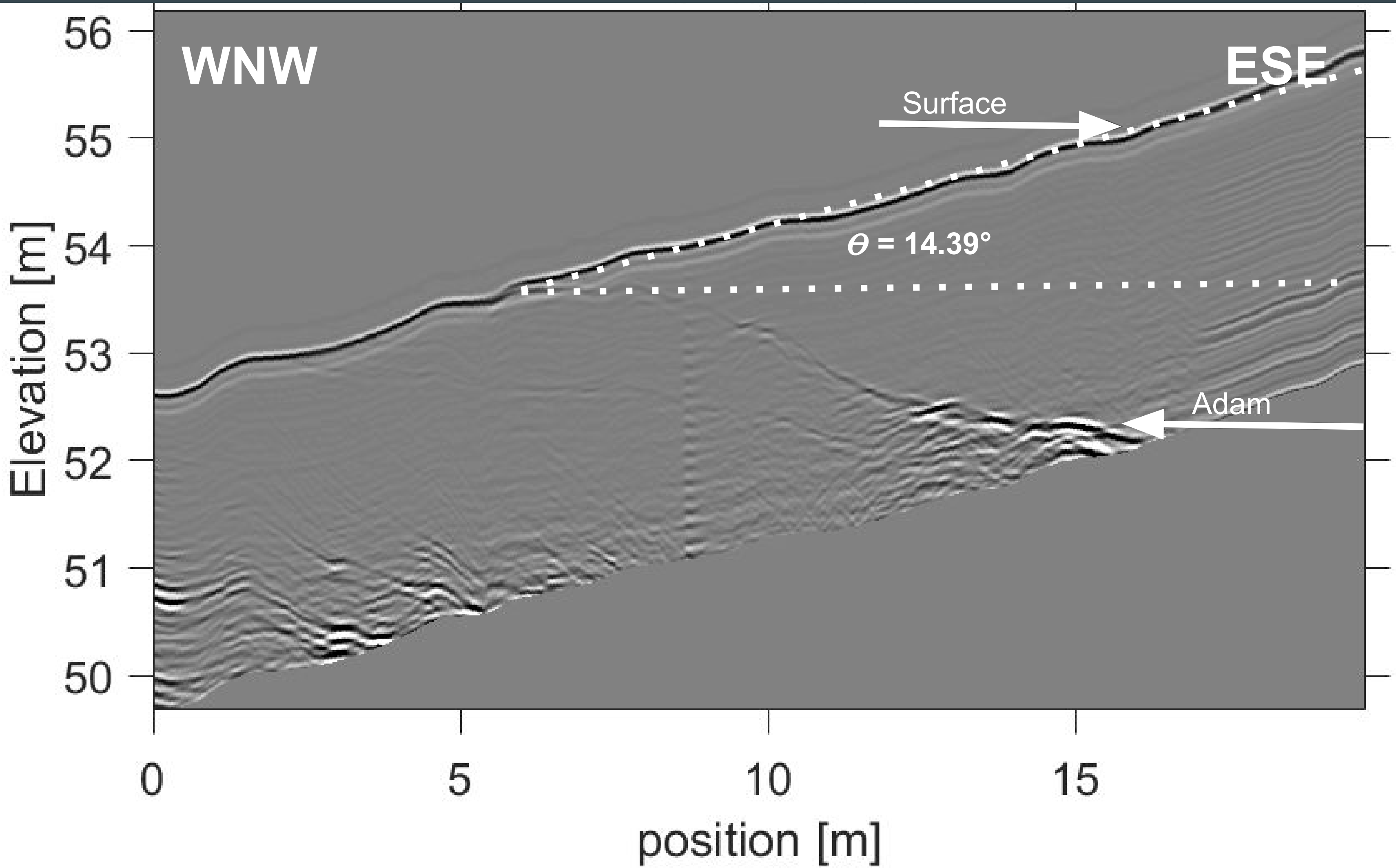

WNW
ESE
Surface
Paleosol A
θ = 13.39°
Elevation [m]
position [m]
56
55
54
53
52
51
50
0
5
10
15


WIND
EAST
"Stoss" Side (Erosional)
"Lee" Side
(Loosely packed)
13°
90



13°
90
Measured slope of paleosol from **perpendicular** transect
Measured slope of paleosol from **parallel** transect


Maximum
Angle of Dip
= 18 degrees
Measured slope of paleosol from **perpendicular** transect
Measured slope of paleosol from **parallel** transect
13°
90



WNW
ESE
Surface
θ = 14.39°
Adam
Elevation [m]
56
55
54
53
52
51
50
0
5
10
15
position [m]

GPR Conclusions

- GPR reveals paleosol topography: bumps on the order of ~1m
- Dip of paleosol “Frederik”: θ = 3° ESE
- Dip of paleosol “Adam”: θ = 13° ESE with the dip of the surface being θ = 9° WNW
  - Estimated max. dip of 18 degrees to NE
  - Lee side of paleodune
  - Wind direction = to NE
- Need to find wind speed!

SEDS Motivation

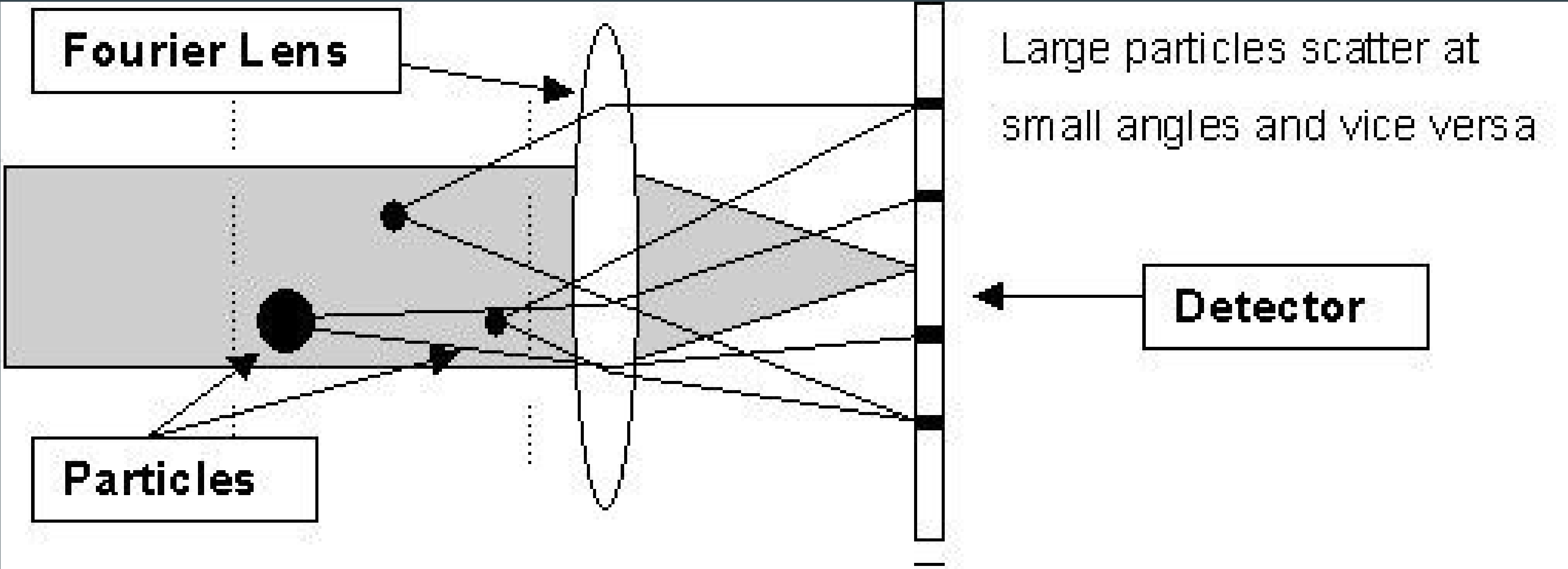
We will look at the grain size diameters in the paleosols to determine wind speed and paleosol composition.

Sedimentology Approach

Sedimentology Approach

Sedimentology Approach

LDPSA Grain-Size Measurement

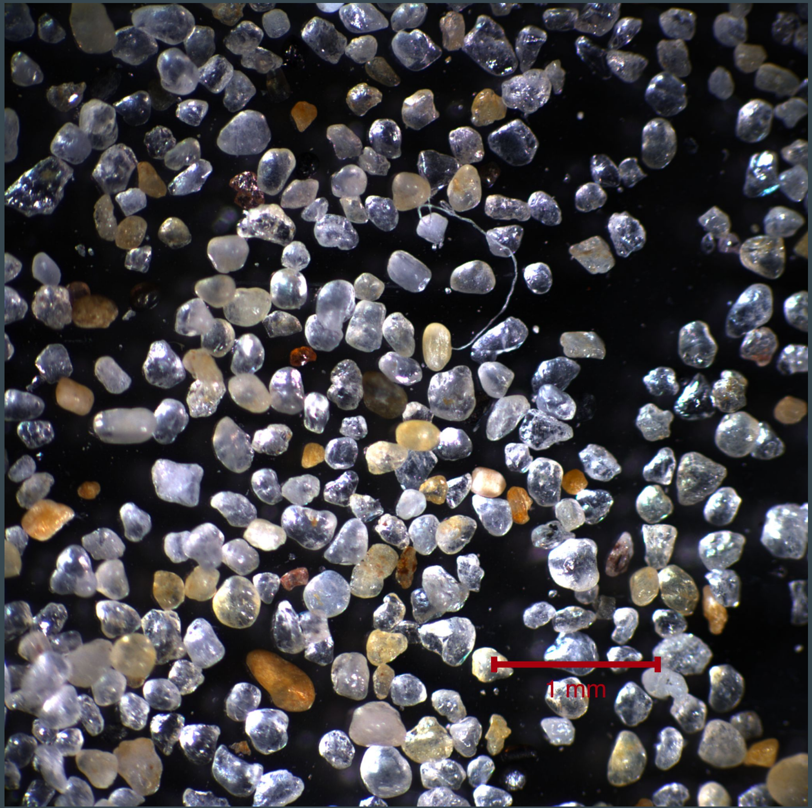


Sand Sample Collection

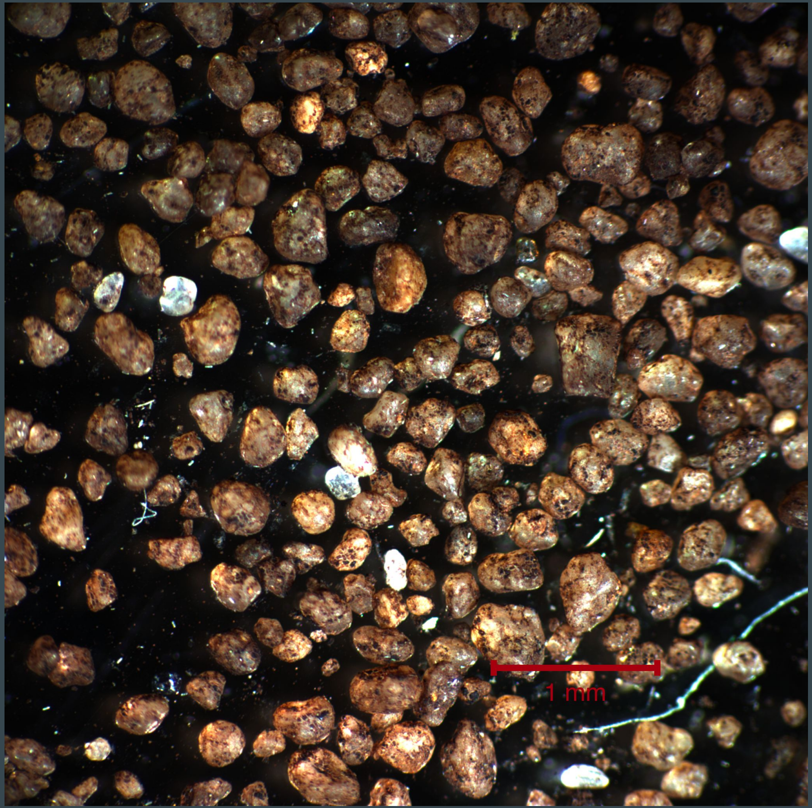
- Excavated cross-section of Adam (top left) and Frederik (bottom right).
- Note color differences in the paleosols

Stereo Microscope Images

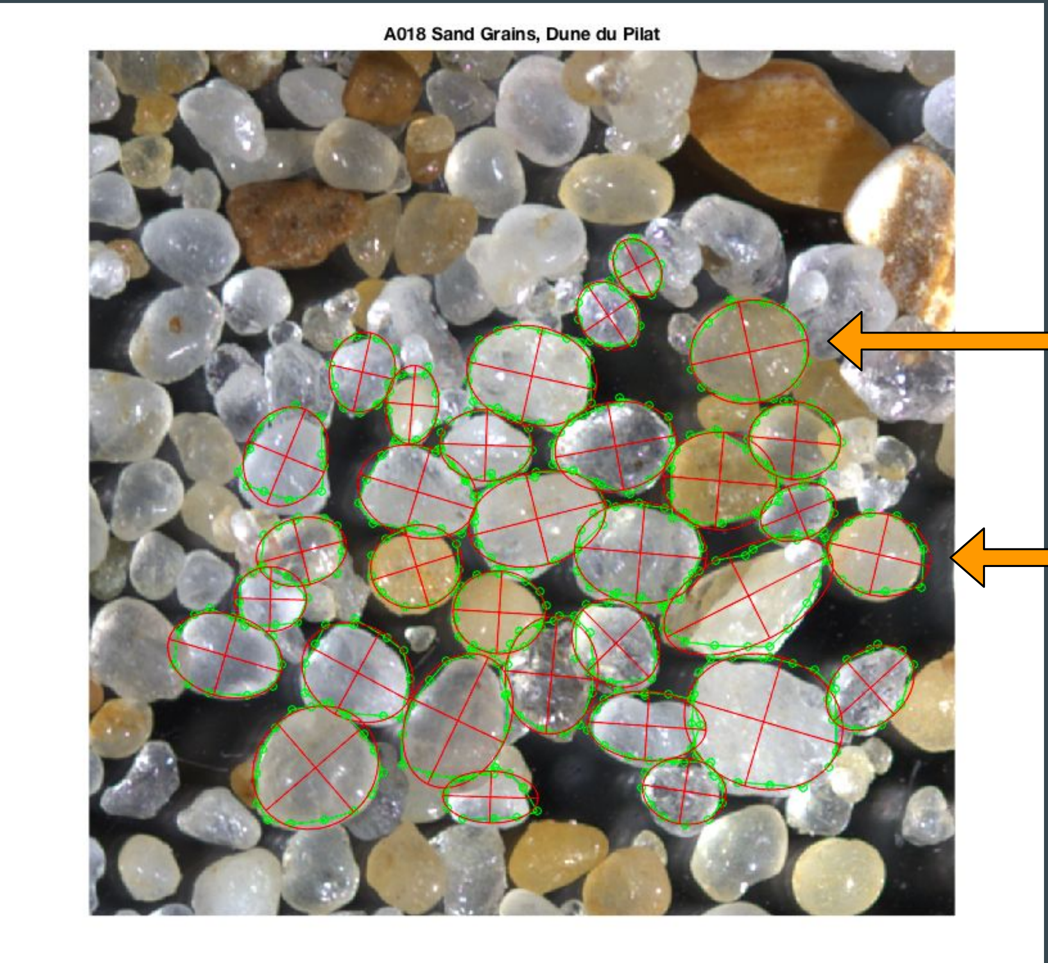
Surface Sand Sample



Paleosol Sand Sample



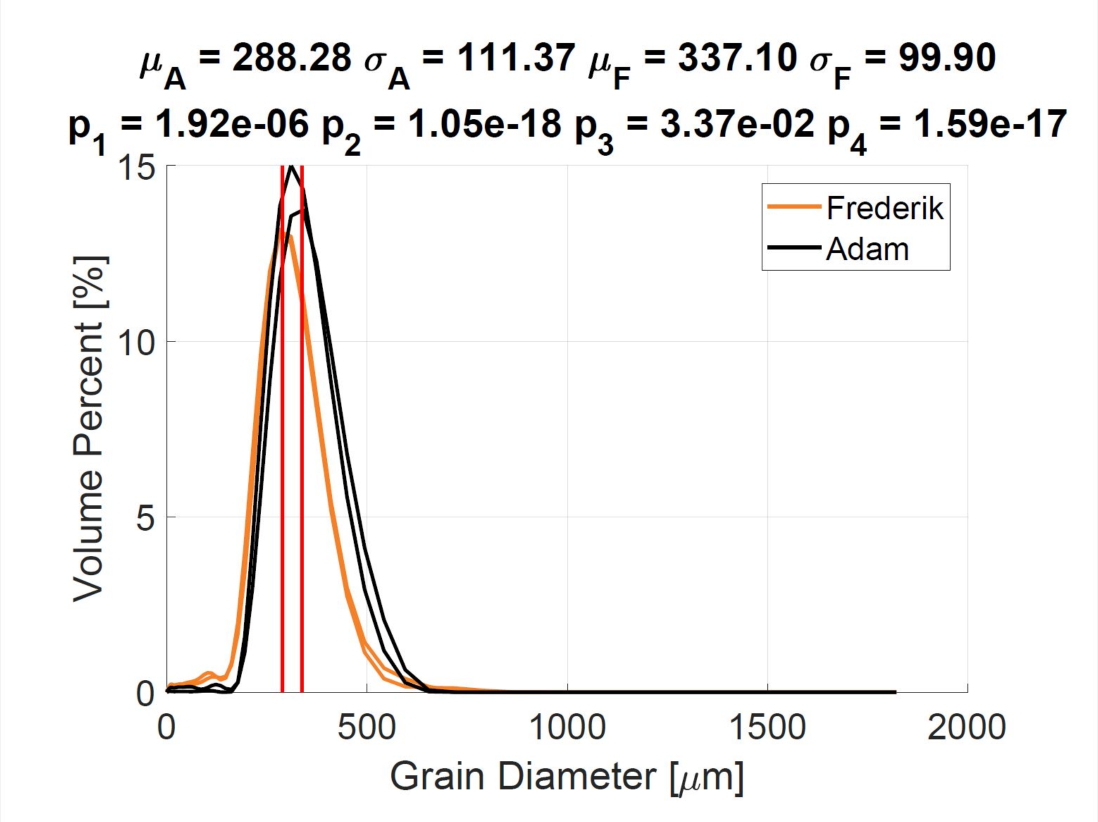
MATLAB: grains.m



Ellipses fitted to individual sand grains

Red lines = ellipse axes

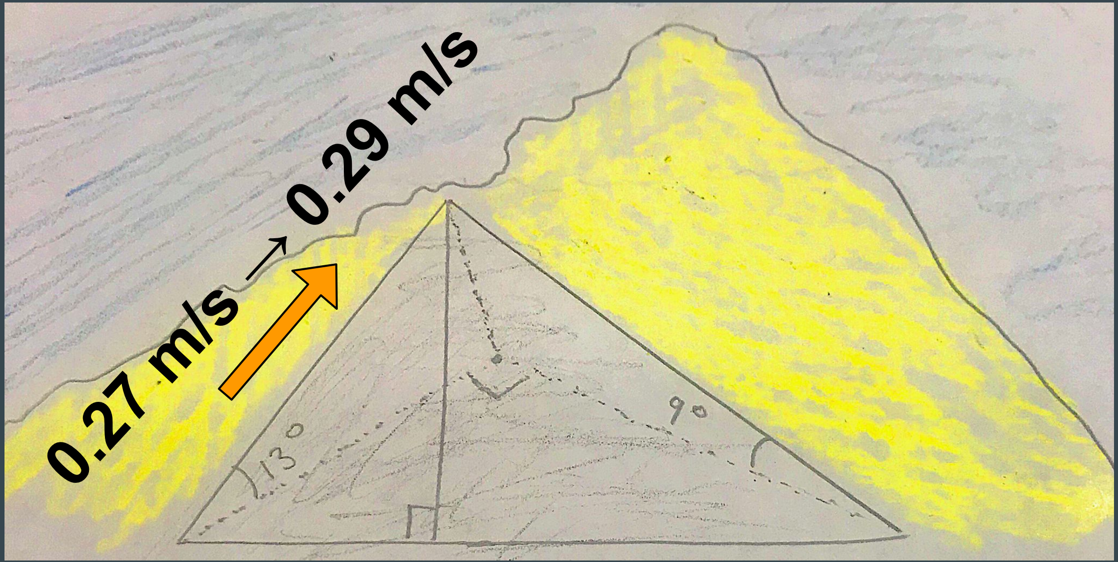
Grain Size Distributions



$\mu_A < \mu_F$

P-values from pairwise Kolmogov-Smirnov tests

Predicted Threshold Erosional Wind Velocity



$$u_{*t} = \sqrt{A_N(\sigma_\rho g d + \frac{\gamma}{\rho d})}$$

$A_N \approx 0.0123; \gamma \approx 3 \times 10^{-4}\text{kg s}^{-2}$

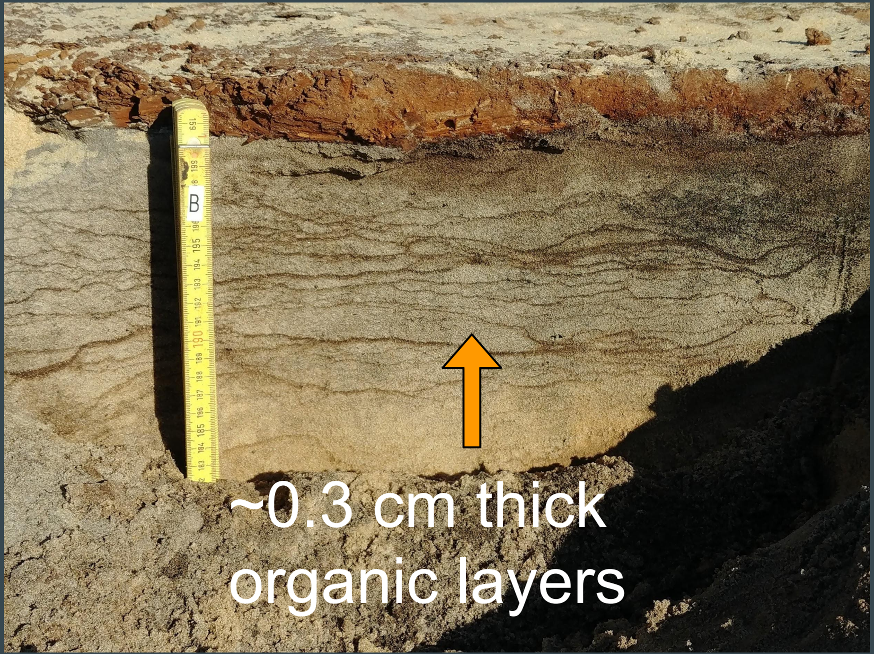
$\sigma_\rho =$ Particle to air density ratio

$d =$ Grain diameter

$\rho =$ Particle density

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

Comparing Paleosol F. and Paleosol A.



SEDS Discussion

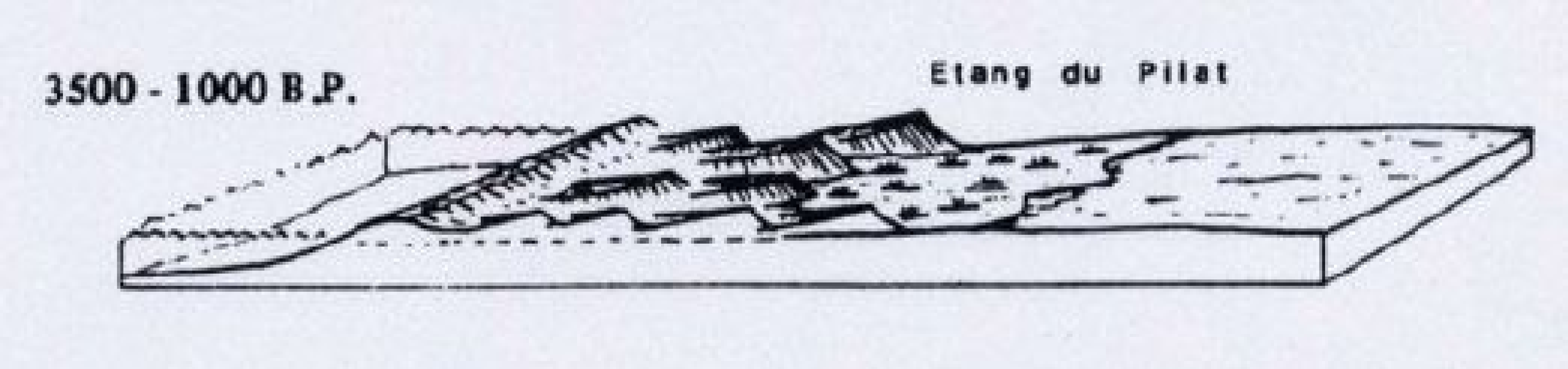


Image: (Barnroff-Nielsen & Willetts, 1991)

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

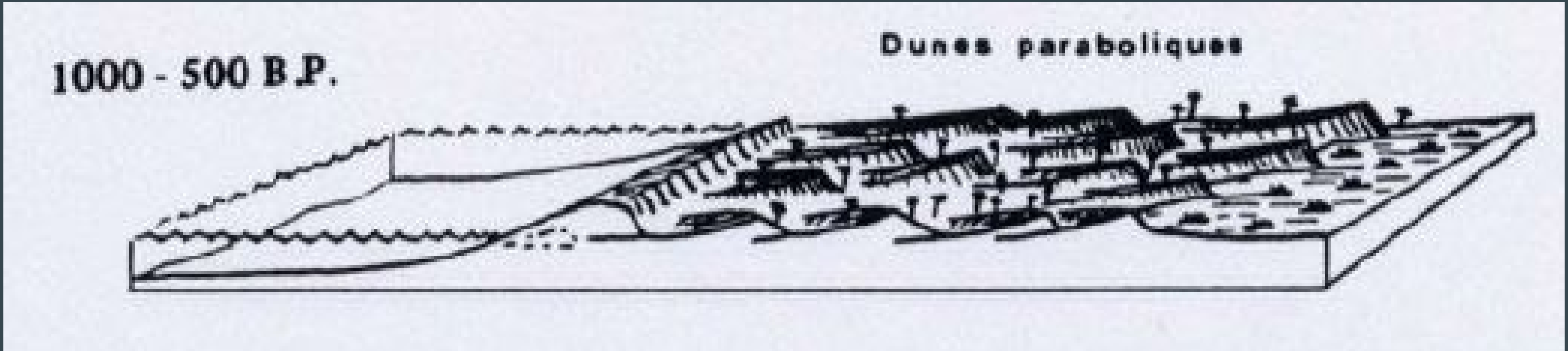
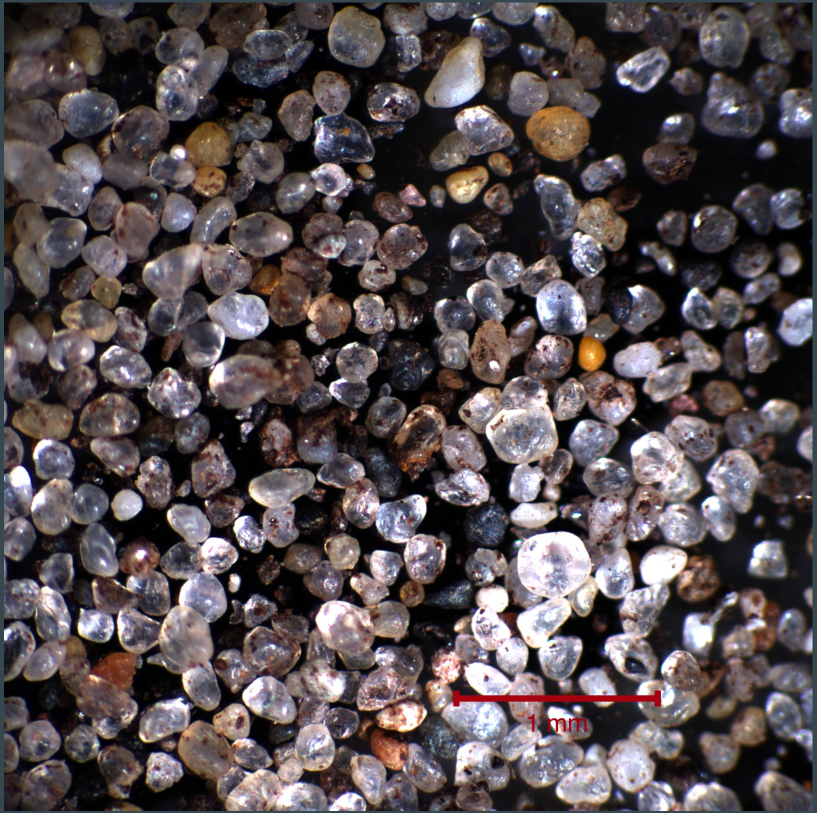


Image: (Barnroff-Nielsen & Willetts, 1991)

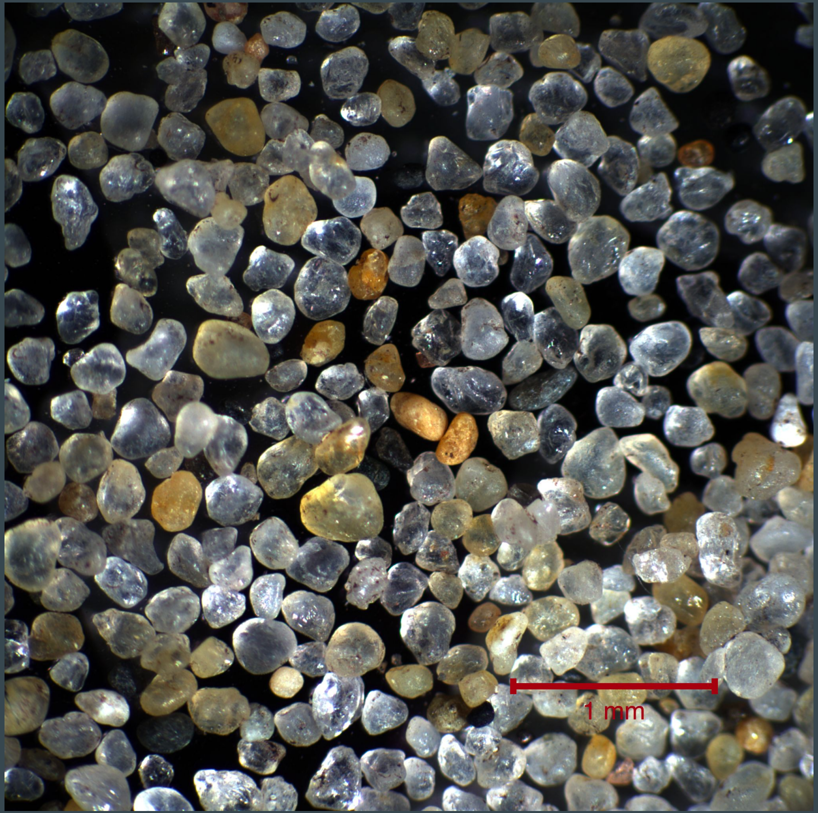
Paleosol “Adam”

- 1000 to 500 years ago
- 20-40 meters in elevation
- Minimum threshold wind velocity: 0.29 m/s

Frederik



Adam



Pinus Sylvestris: found in first and second paleosol

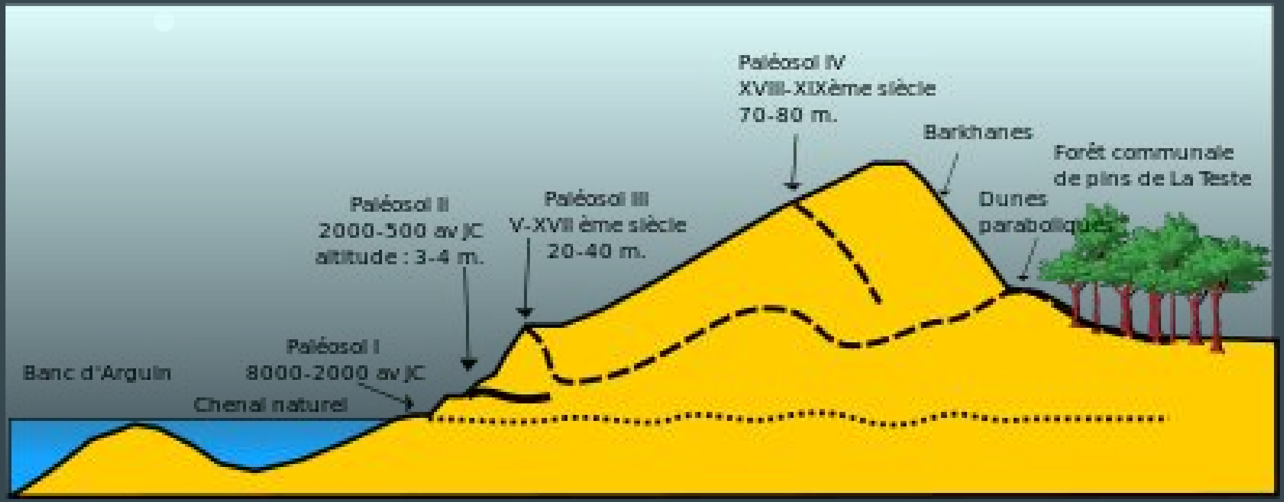
Image: http://www.greenart.com/plants-exped-SW-France-part1-forests.html

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!

http://www.dune-pyla.com/en/construction-of-the-great-dune-of-pyla-history.html

Acknowledgements

We would like to thank Frederik Simons and Adam Maloof for helping us throughout FRS 135 and guiding us toward designing and analyzing our research. Thank you to Sujith Ravi and Paul Choi from Temple University for allowing us to use the LDPSA to measure sand grain analysis. Thank you to Emily Geyman and Alex Burky for taking the time to guide us individually in our projects on the field and helping us to analyze the data later. Finally, thank you to the FRS class for helping us on the field and at Princeton with our research.

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