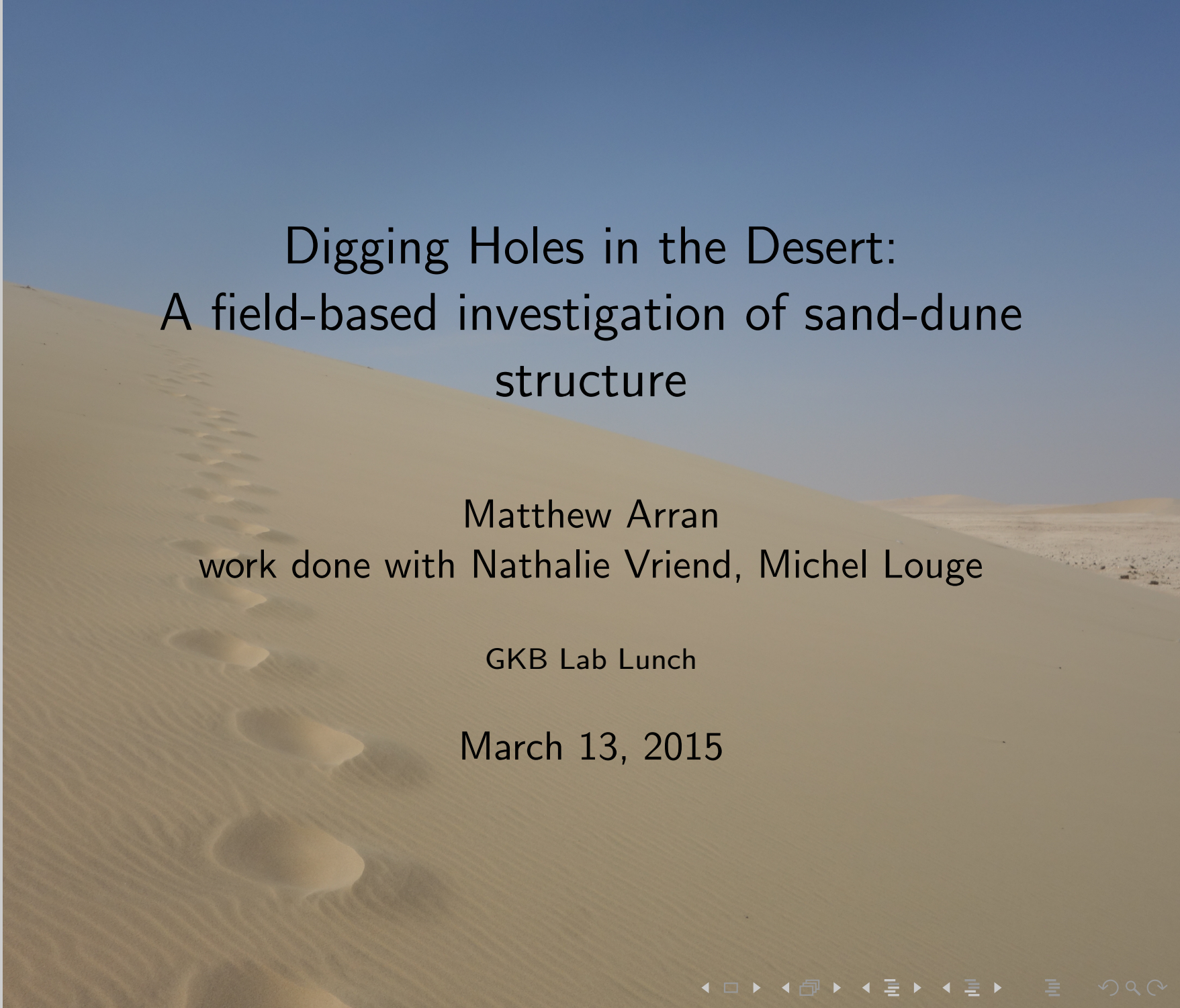


Digging Holes in the Desert: A field-based investigation of sand-dune structure

Matthew Arran

work done with Nathalie Vriend, Michel Louge

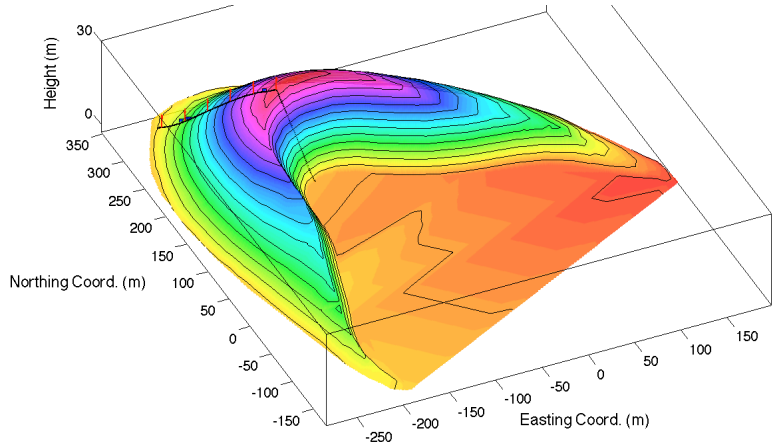
GKB Lab Lunch

March 13, 2015

Introduction

Structure: Observation and relevance
Possible mechanisms for layering
Field Investigation
Preliminary Results
Further Work

Observations



Credit: Prof. M. Louge, Jan 2015

Observations

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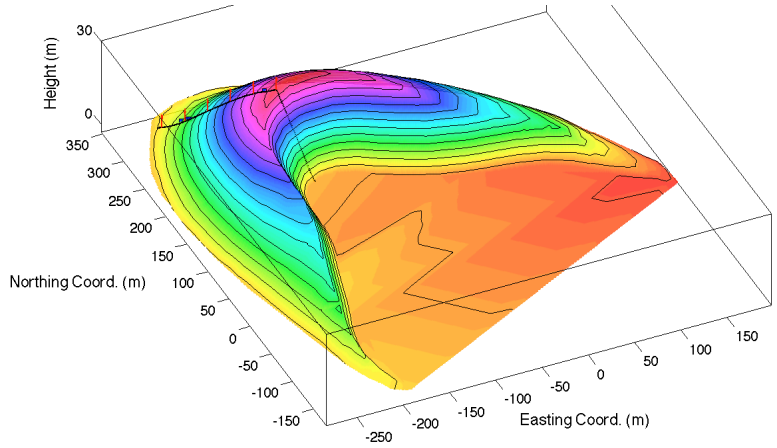

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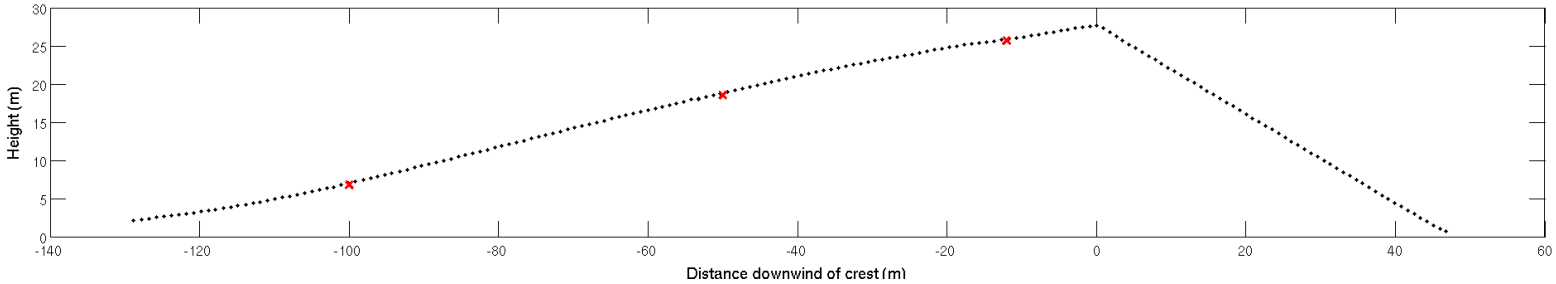

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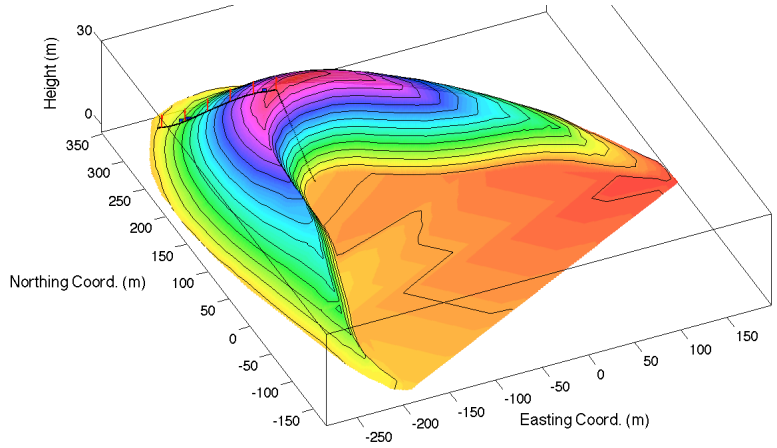

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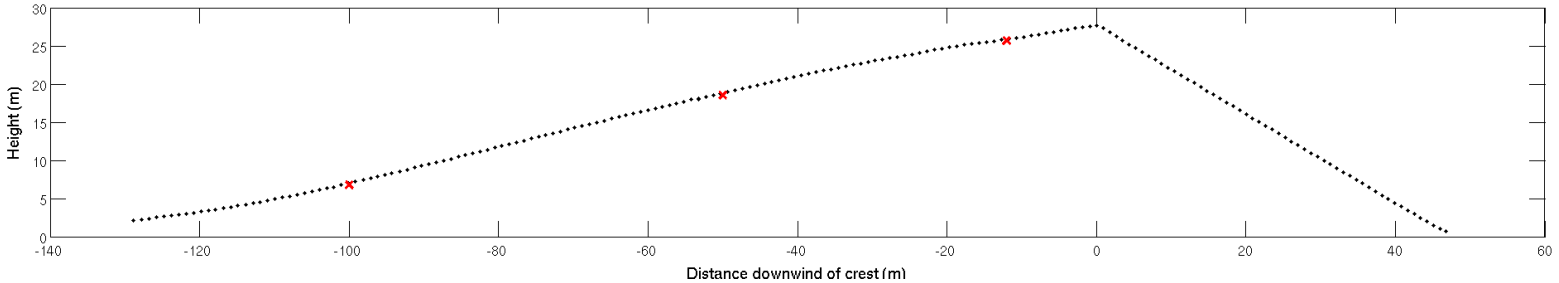
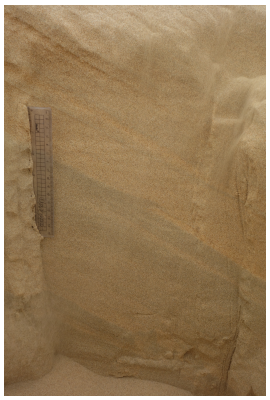
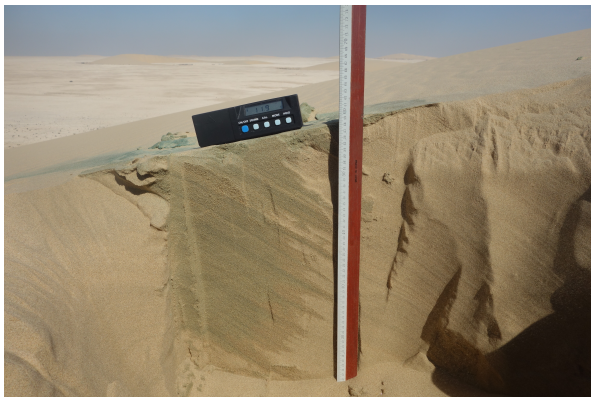
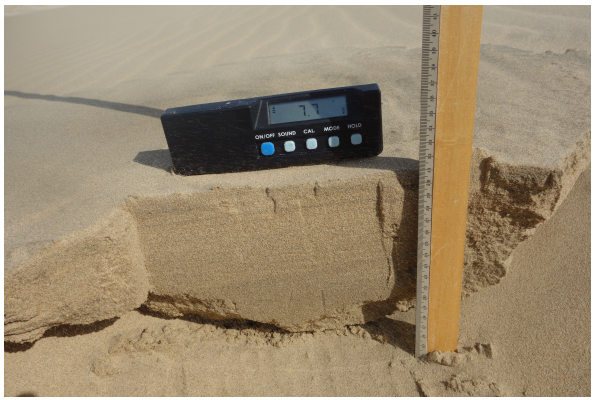






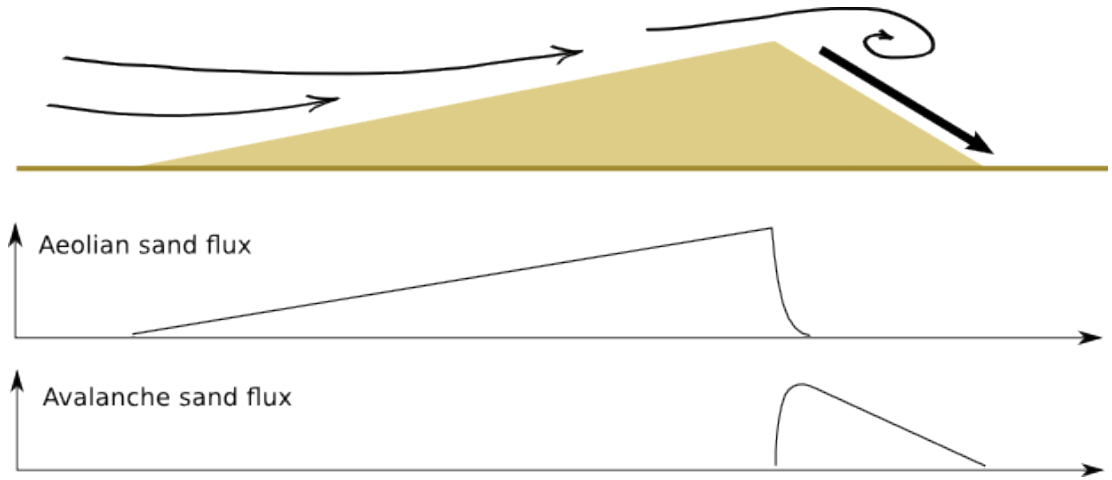


Relevance

- Oil and gas recovery
- Desert hydrology
- Microbiological dune stabilisation
- Interpretation of sandstones
  1. Environment of deposition
  2. Climatic conditions

Dune Migration

- Migration is via two mechanisms:
  1. Aeolian transport
  2. Slip-face avalanches
- Segregation is associated with both processes:
  1. Differential transport under variable wind conditions
  2. Kinetic sieving and squeeze expulsion



Threshold velocity

- Consider aeolian transport in inviscid regime

$$Re_p = \frac{u_* d}{\nu} \gg 1 \qquad \text{for} \begin{cases} \text{shear velocity } u_* = \sqrt{\tau/\rho_a} \\ \text{particle diameter } d \end{cases}$$

- Ratio of destabilising to stabilising forces on a particle the Shields' number

$$\theta = \frac{\rho_a u_*^2}{(\rho_s - \rho_a) g d} \qquad \text{for} \begin{cases} \text{air density } \rho_a \\ \text{sand density } \rho_d \end{cases}$$

- Therefore threshold shear velocity $u_{*t} \propto \sqrt{d}$

Sand flux

- Above threshold velocity, in steady conditions, time-averaged sand flux

$$Q \approx \frac{C_b \rho_a}{g} \sqrt{\frac{\bar{d}}{d_{ref}}} u_*^3 \qquad \text{for const. } C_b, d_{ref}$$

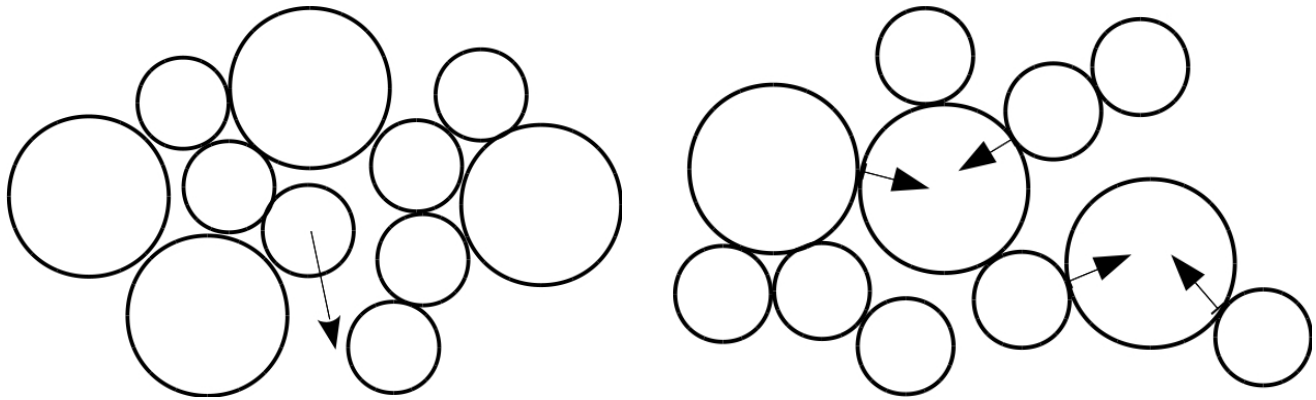
- Fraction of flux consisting of particles of diameter d, making up mass fraction M_d/M of source,

$$\frac{Q_d}{Q} \approx \gamma_1 \left(\frac{d}{\bar{d}} \right)^{-\gamma_2} \frac{M_d}{M} \qquad \text{for const. } \gamma_1, \gamma_2$$

- But wind conditions fundamentally turbulent, unsteady
- Complex dependence of transported particle size distribution on source distribution, wind conditions

Kinetic sieving and squeeze expulsion

- Consider particle-level motion in avalanche
- Kinetic sieving:
  1. Smaller particles may fall through smaller voids
  2. Systematic downwards flux of smaller particles
- Squeeze expulsion:
  1. More frequent collisions at higher local particle density
  2. Size-unbiased, diffusive, upwards flux of particles

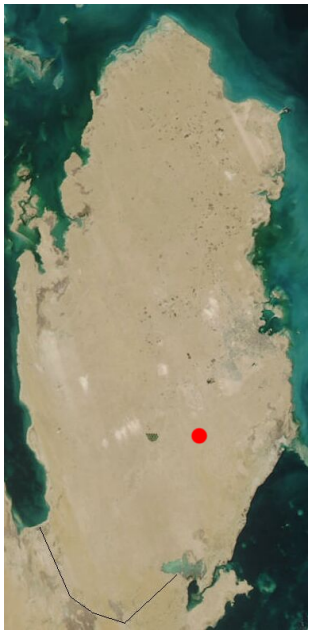


Distinguishing features

- Magnitude of each effect hard to calculate directly
- Timescales also difficult to quantify
- Layer thickness
  1. Set by wind variation timescale, dune migration rate
  2. Set by fundamental avalanche processes
- Grading in layers
  1. Varies depending on wind variation
  2. Consistent inverse grading

Approach

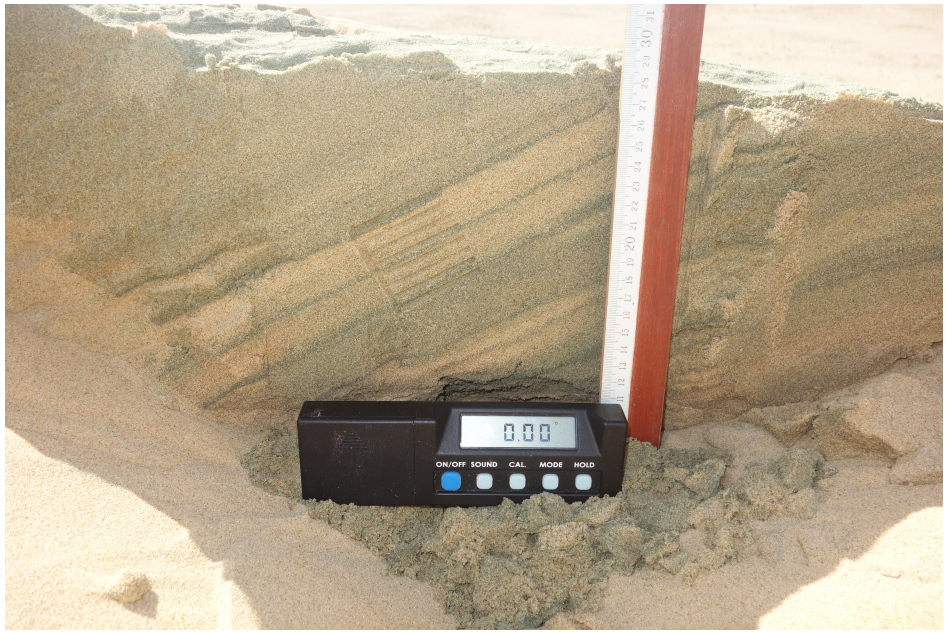
- Fieldwork conducted between Doha and Messaieed, Qatar
- Two dunes in dune field studied
- Theodolite and ground penetrating radar surveys
- Samples taken with 'comb' and 'aquarium'



Satellite images courtesy of NASA, CNES/Astrium, Google

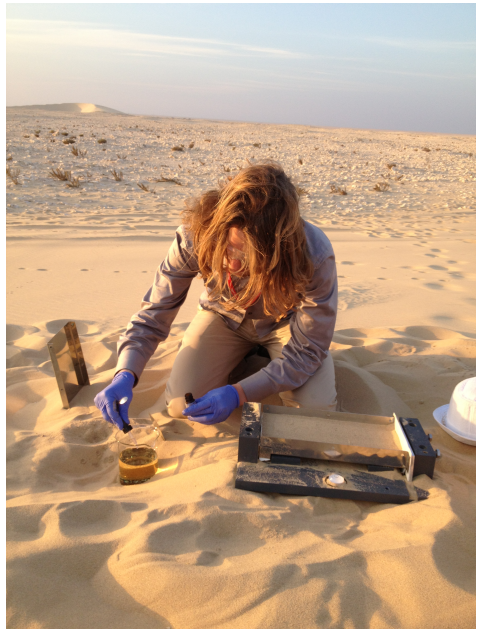
'Comb' samples

- Sand wetted for cohesion and pit dug
- Seven adjacent 7mm wide samples extracted
- Size analysis by laser diffraction particle sizer



'Aquarium' samples

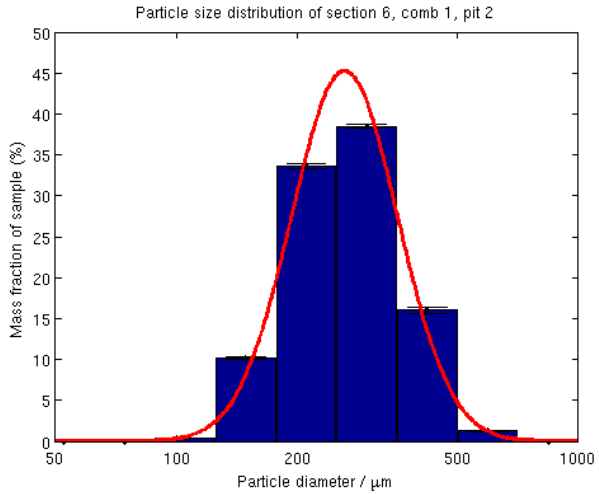
- Cuboidal 'aquarium' inserted into undisturbed sand
- Pit dug and 'aquarium' extracted
- Front plate removed
- Low viscosity acrylic resin added and allowed to set
- Sample removed and cut into sections
- Images to be taken with reflected light microscope
- Images to be analysed for particle size distributions

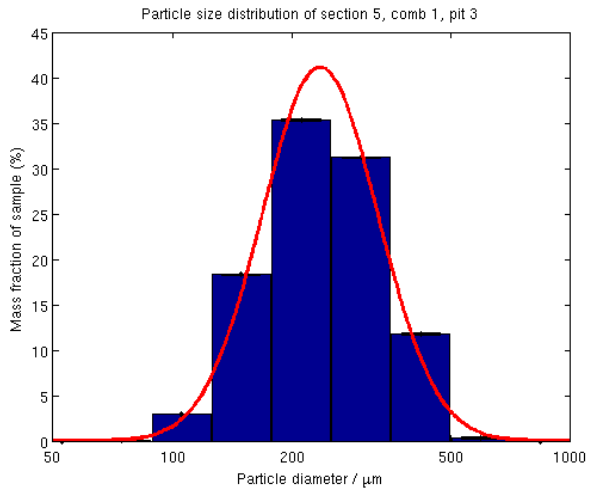


Photos courtesy of Prof M. Louge

Single sample size distribution

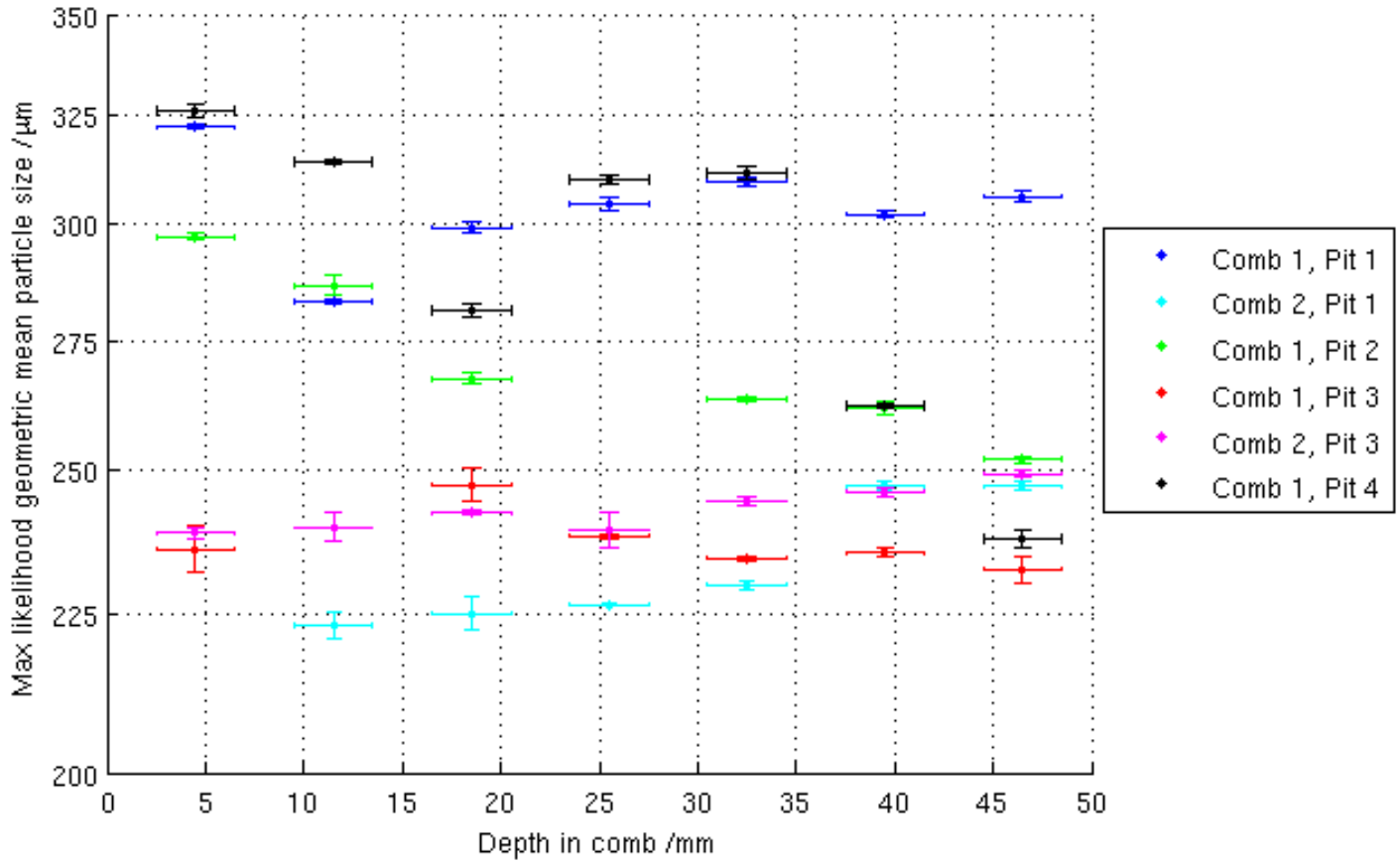
Particle size distribution in each sample lognormal, with clear max-likelihood location and shape parameters.





Comparison of location parameters

- Variation between layers greater than in each layer
- No distinct inverse grading observed in grainflow layers
- Grading in aeolian layer similar to that in grainflow layers



Questions raised

- Variation along a single layer?
- Visual distinctiveness of layers?
- Systemic error?

Further work

- 'Aquarium' sample analysis
- GPR survey comparison
- Comparison with site data
  1. Weather station data
  2. Sand trap data
- Comparison with lab experiments
  1. Avalanche depth distribution
  2. Extent of segregation
- Theoretical modelling

Acknowledgements

- NERC, QNRF
- WCMC-Q, Department of Earth Sciences, Department of Geography
- Prof. Michel Louge, Dr. Ali Sultan, Prof. Anthony Hay, Prof. Anil Netravali
- Paul Mitton, David Page-Croft, Martin Walker, Chris Rolfe

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