Toward Modelling of Natural Deposits at Grain Scale: 3-D X-Ray CT Characterization and Study of Fabric Evolution in Naturally Deposited Sands

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Our Objective

- **Use X-RAY Computed Tomography to Characterize Fabric:**
  - Grain size, grain shape, grain aspect ratio
  - Quantify grain fabric i.e. geometry of grain to grain contacts, contact area, etc.
  - Observe Shear Zone Evolution

- **Develop Level Set – DEM models to numerically reproduce**
  - Fabric as observed in the scans
  - Stress-strain response
  - Develop a realistic constitutive model that adequately mimics the influence of fabric under different loading conditions, especially liquefaction.

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Where Does Fabric Come Into Play?[1]

Type of Deposit:

- Source of the sediment
- Mode of transport
- Depositional environment
- Post-Depositional processes – Geologic history

Soil Fabric:

- Gradation
- Grain shape and aspect ratio
- Grain orientation
- Geometry of grain to grain contacts
- Cementation/Matrix

Influence of Fabric

[1] **Terzaghi, K., "Influence of geological factors on the engineering properties of sediments, 50th Anniversary Volume, Econ. Geol., 1955, pp. 557–665.**

Gravel Beach, No apparent preferred orientation but well packed
Kapiti Island, NZ

Glacial outwash, imbricate fabric, clear preferential orientation
Bountiful, Utah

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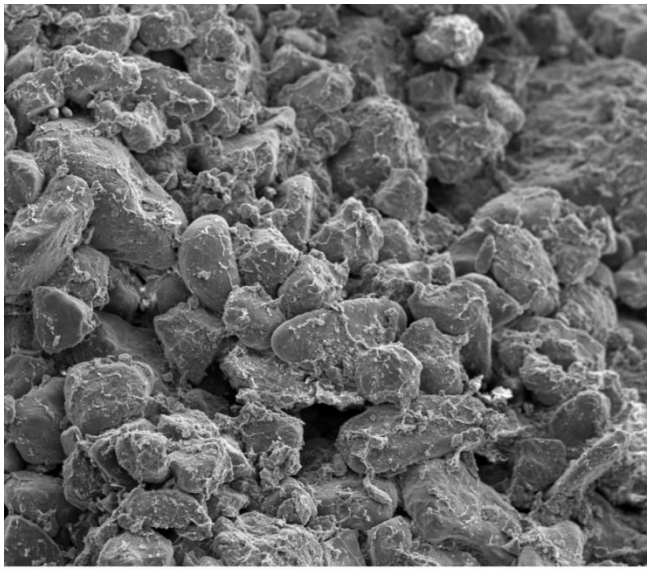
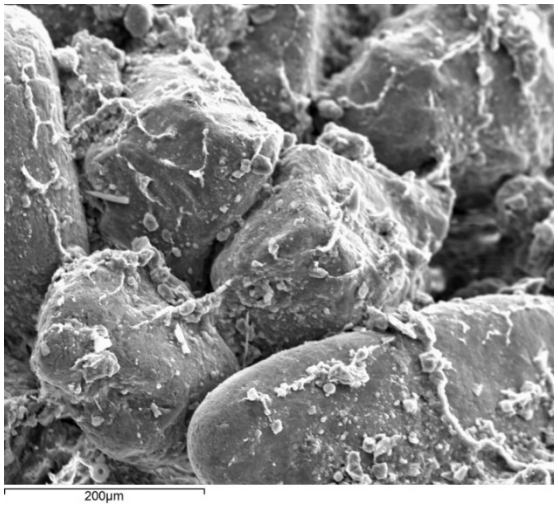
Treasure Island, SF Bay – constructed by hydraulic filling in 1939
Recent study shows a significant difference in liquefaction resistance between the hydraulic fill and underlying natural sand bar – fabric?





SEM scans of sand bar samples from SF Bay, CA (courtesy ENGEO)

Note the intimate packing of the grains in the natural deposit

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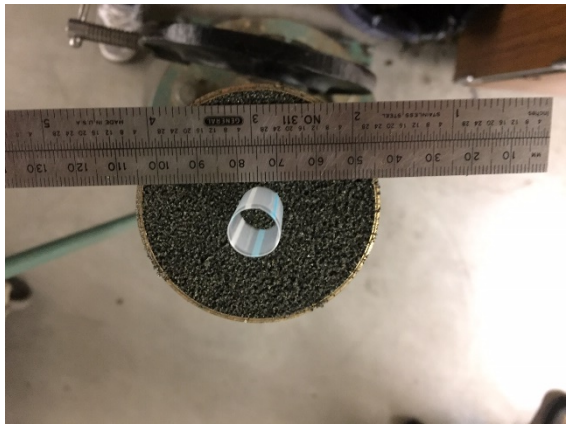
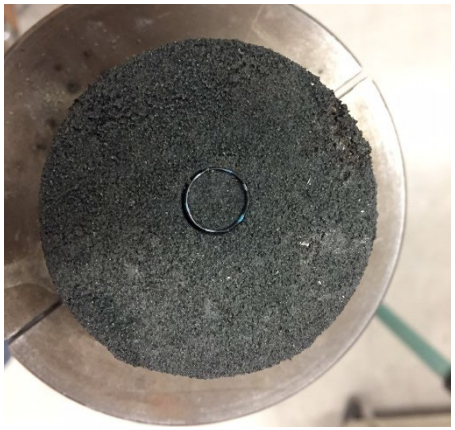
“ Undisturbed” Sampling Procedure

- Objective - Obtain 11 mm ”undisturbed” thinwall samples for X-Ray tomography and triaxial testing

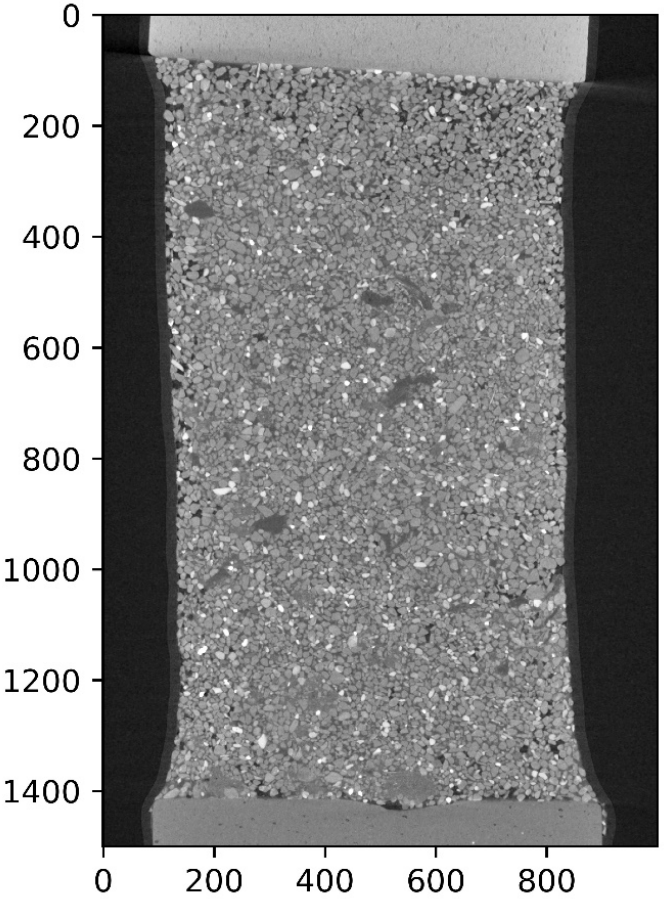


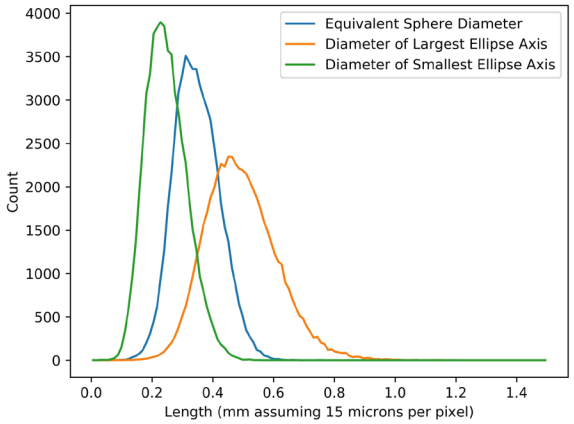


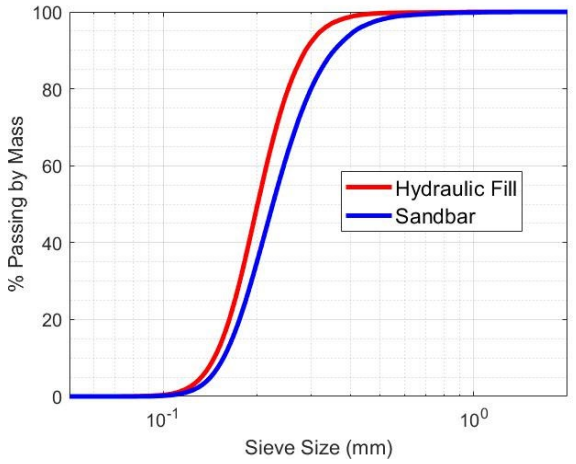
3-D X-Ray Computed Tomography

Laboratoire 3SR - Sols, Solides, Structures, Risques at the University Grenoble Alpes
Prof. Cino Viggiani and Dr. Edward Ando - collaborators

- Fabric Characterization – Grain size, grain size distribution







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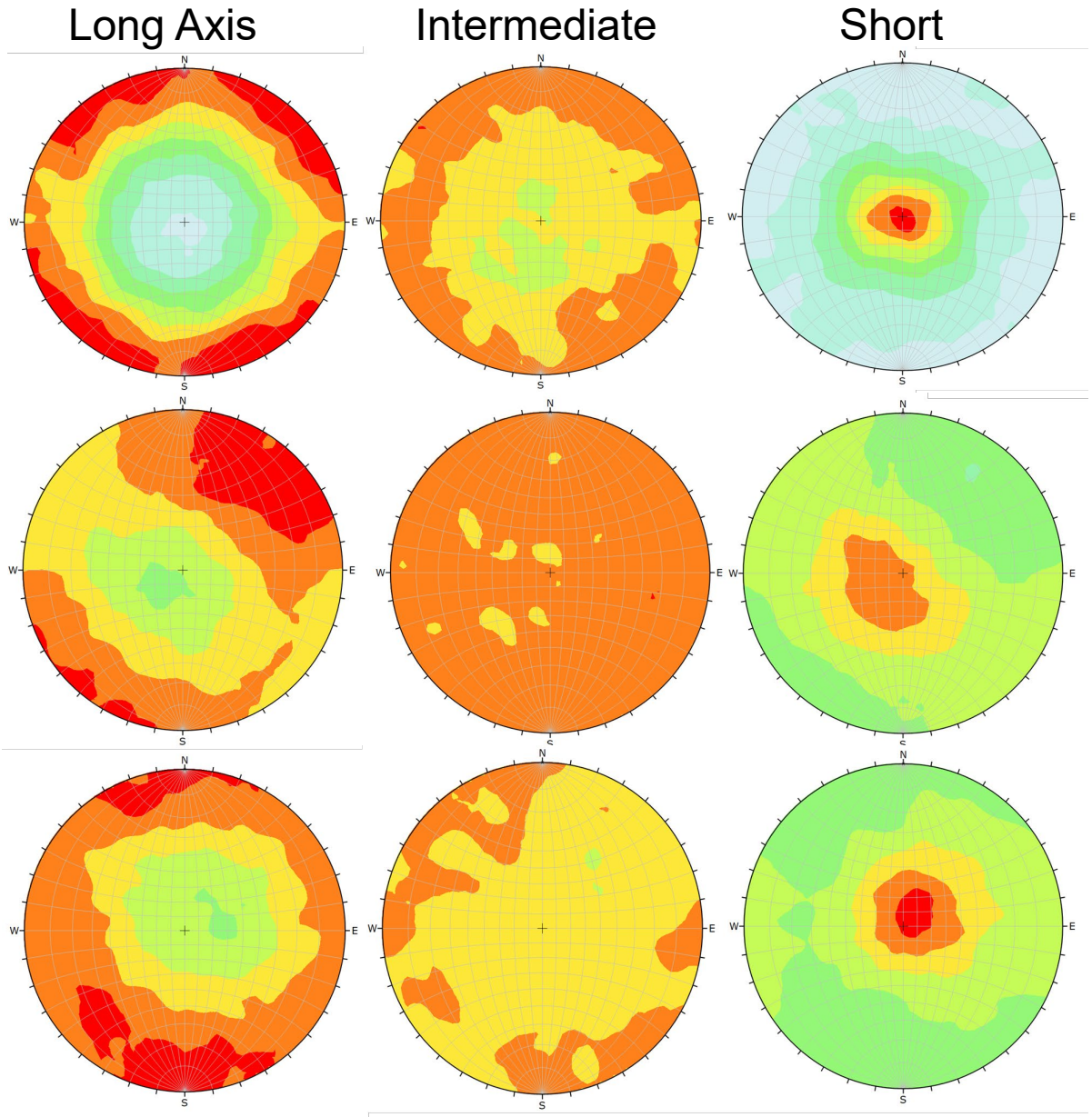
Quantitative Grain Orientation Analysis



Pluviated
in the Laboratory
Viggiani et al.

Hydraulic Fill
Undisturbed
Treasure Island

Sand Bar
Undisturbed
Treasure Island

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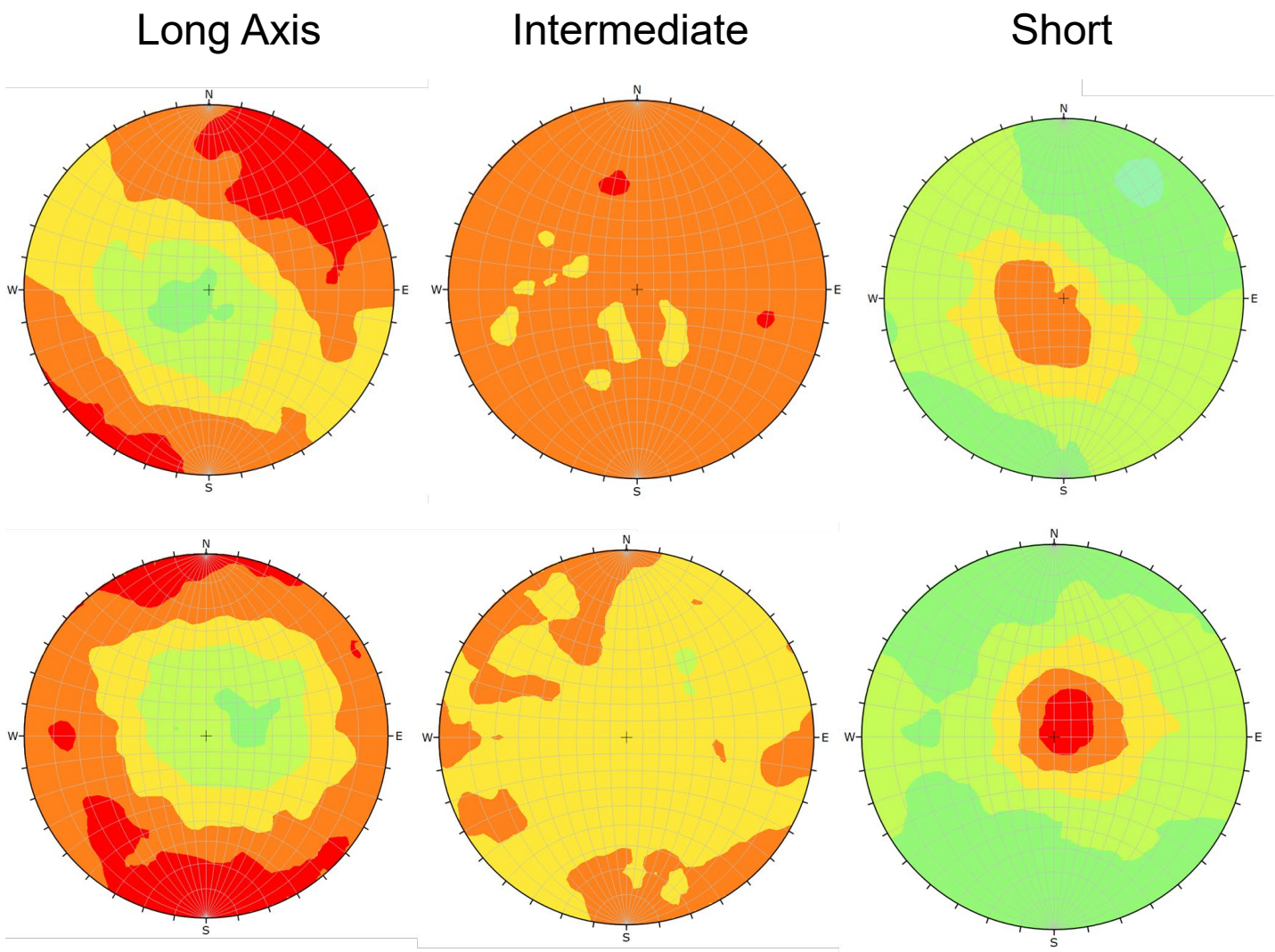
Grain Shape Analysis – Sphericity <.85



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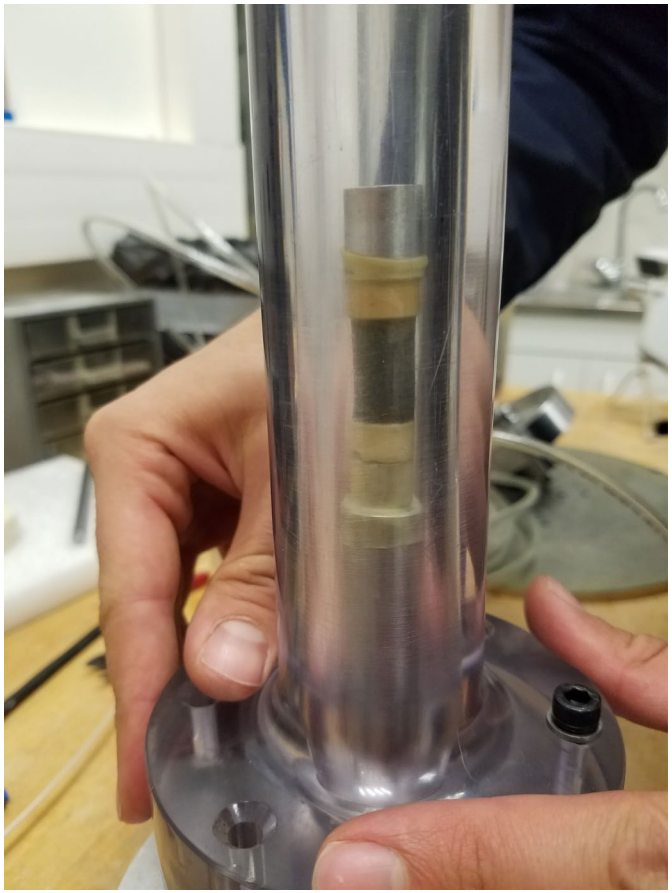
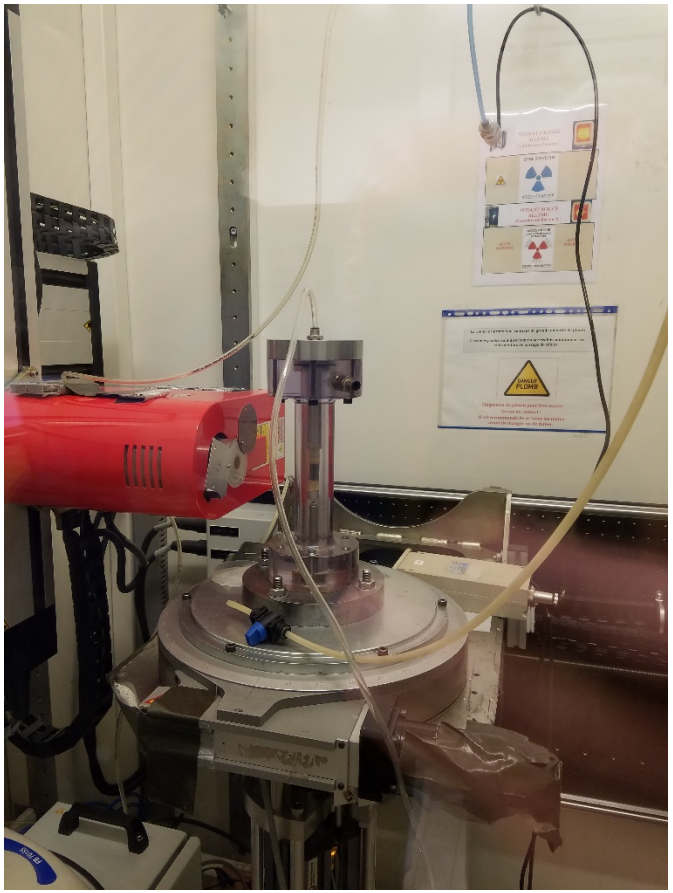
Vacuum Triaxial Test Configuration at Laboratoire 3SR





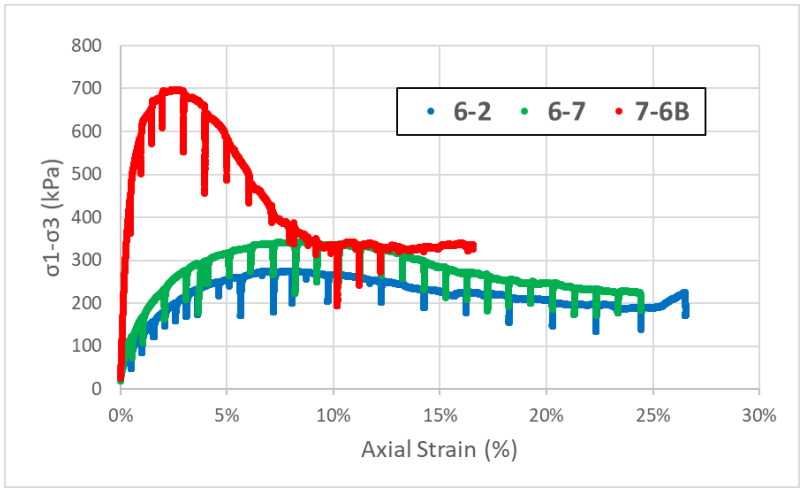
Triaxial Test Results – Sand Bar Deposit

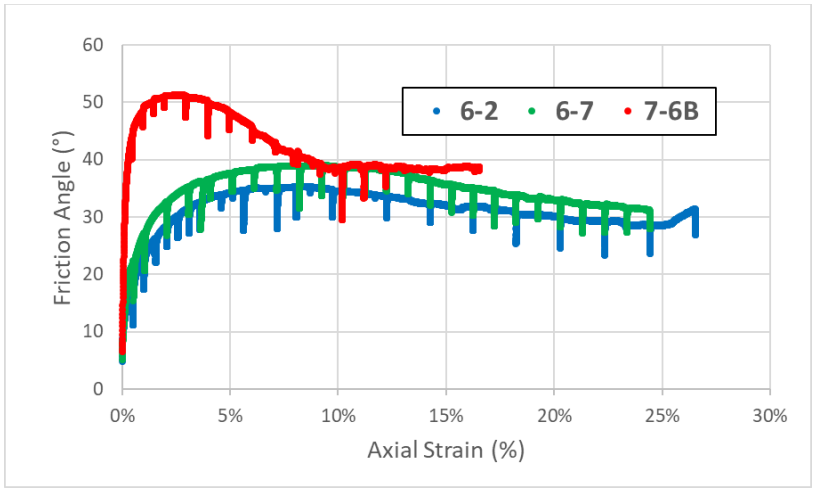
Confining Pressure = 100 kPa
Dry Unit Density = 16.17 kN/m^3 (103.8 pcf)
Void Ratio = 0.61

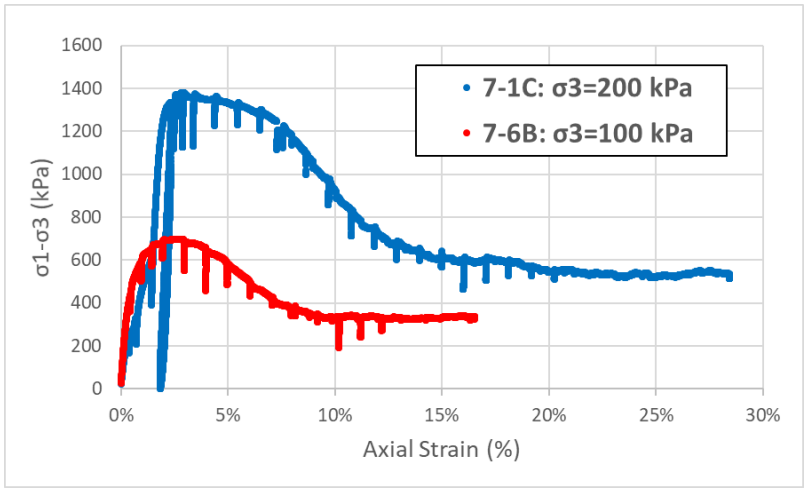
Triaxial Test Results – Sand Bar Deposit

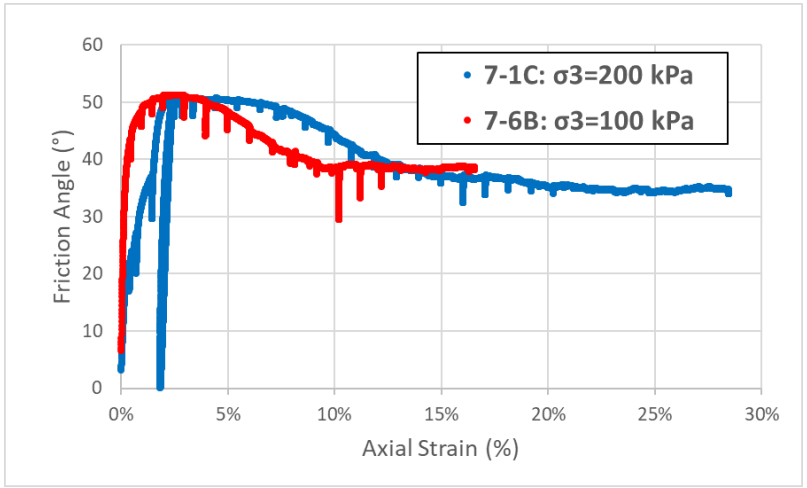
Confining Pressure = 200 kPa
Dry Unit Density = 16.17 kN/m^3 (103.8 pcf)
Void Ratio = 0.61

Triaxial Test Results – Sand Bar vs Hydraulic Fill









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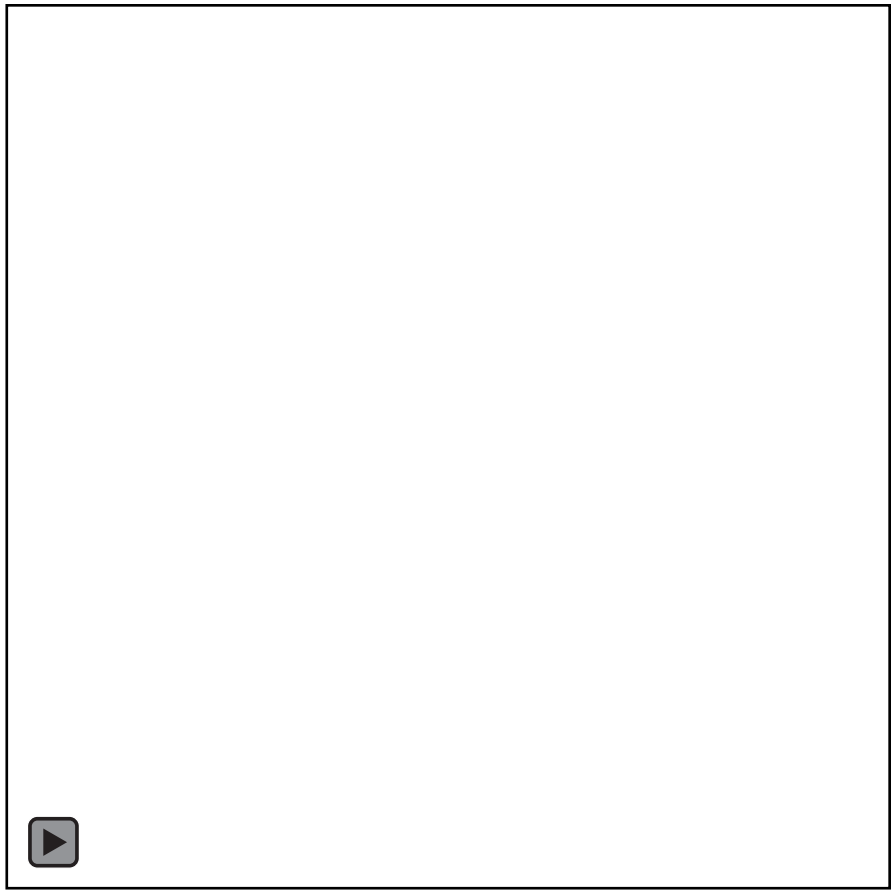
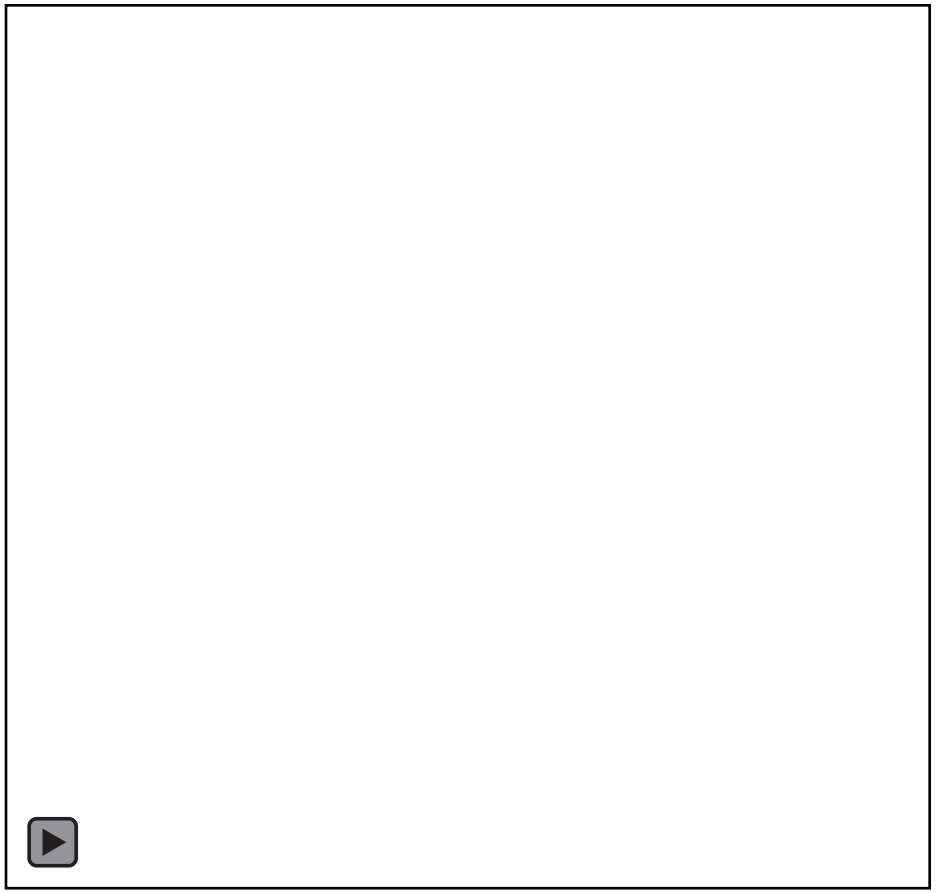
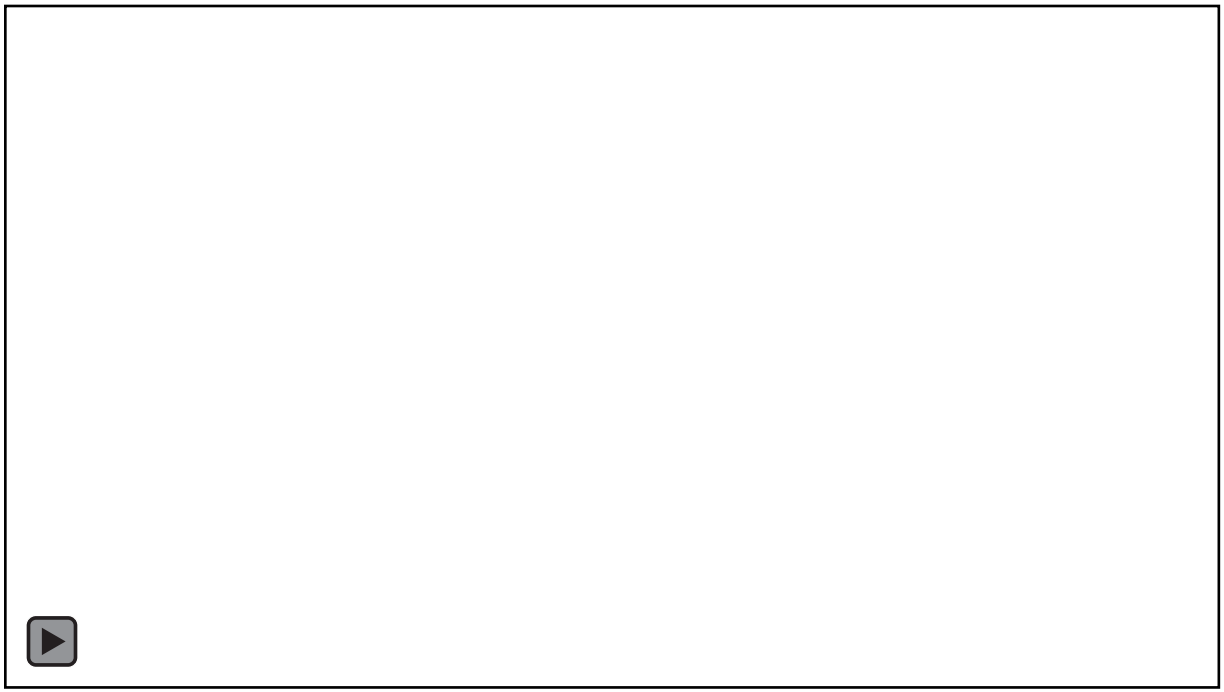
Shear Plane Evolution





3-D Reconstruction from X-ray Tomography



HPC Resources	Savio (Berkeley) Stampede2 (UT Austin)
# Grains	100,000-120,000
Resolution	7.5-15 µm/pixel
Memory Required	128 GB
# Cores	Serial (~6 hours/image x 15-24 images on Stampede2)

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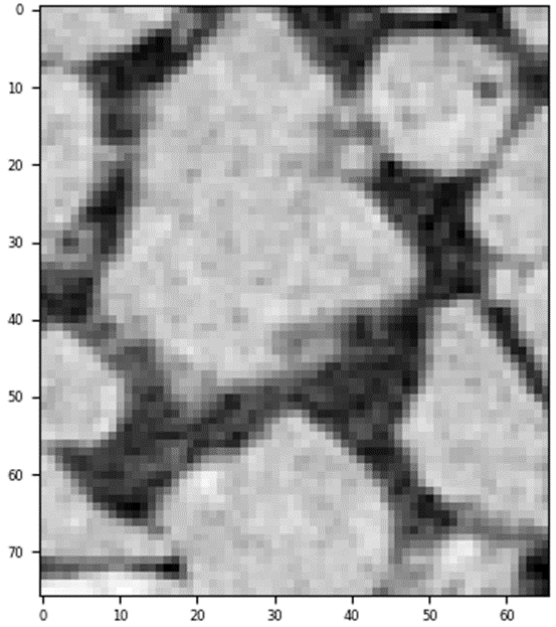
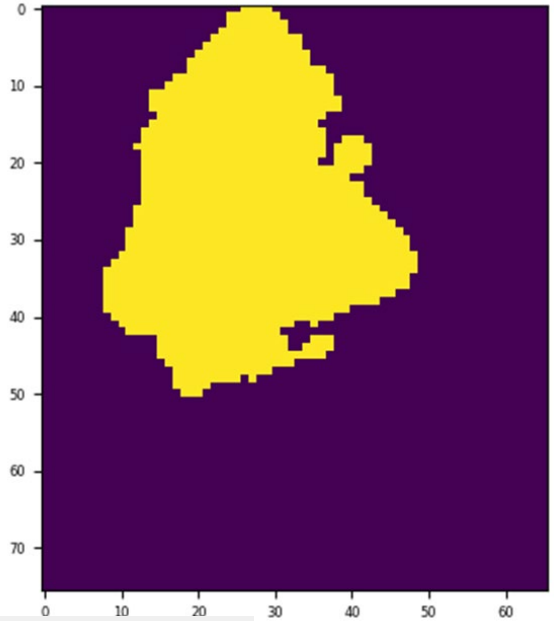
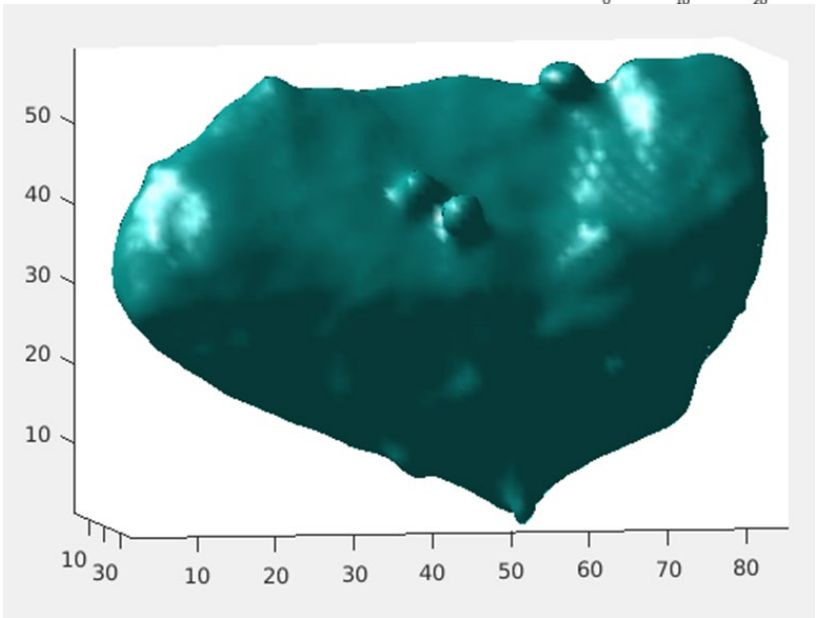
Converting X-Ray CT Scans to Avatars for DEM Model – high resolution grain with “warts”, artifacts from clay adhesions







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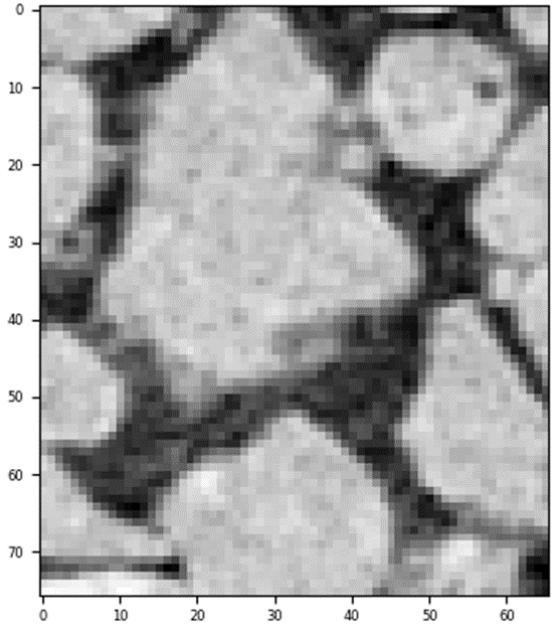
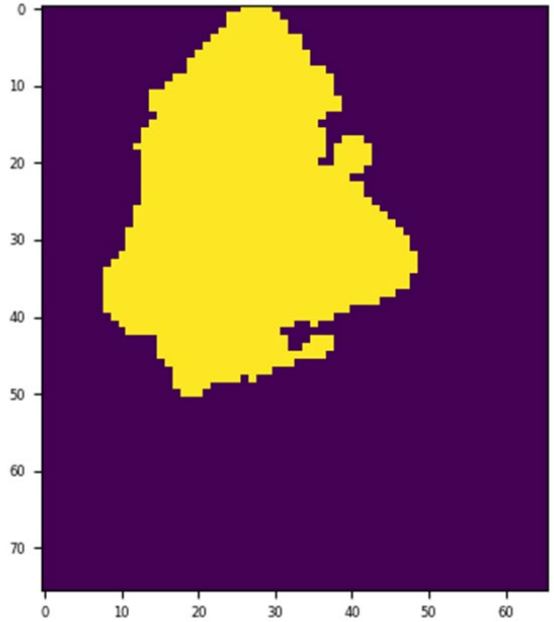
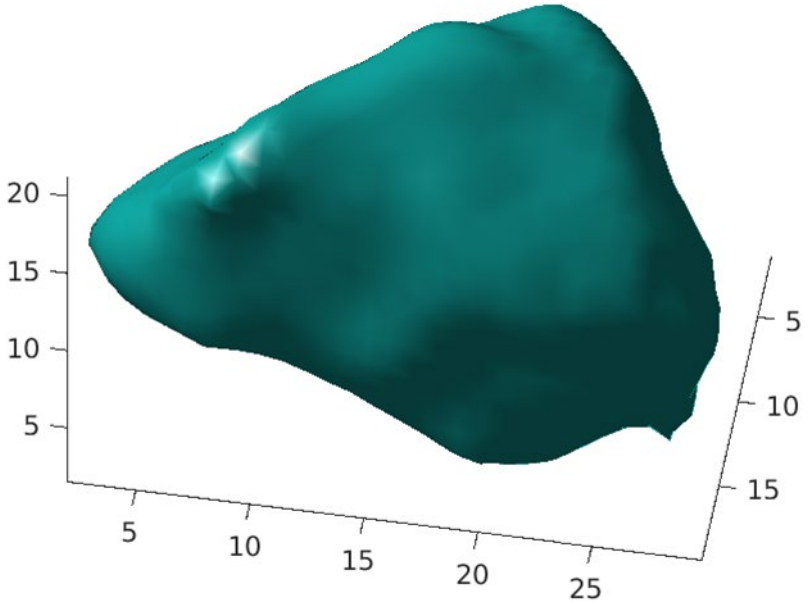
Converting X-Ray CT Scans to Avatars for DEM Modeling – low resolution without artifacts







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Results to Date

- We developed a procedure to collect undisturbed samples for 3-D XRCT
- We performed the first triaxial tests on undisturbed samples showing that natural sand bar deposits show much higher apparent friction angle due to the presence of fabric
- Fabric studies show that in while packing is clearly different, grain sphericity masks any preferential depositional fabric, i.e. imbrication is not dominant in the deposits we analyzed

Current Effort

- Developing realistic avatars in order to recreate the fabric
- Next step: LS-DEM modeling to reproduce the observed tests and then to validate/develop constitutive models

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Acknowledgement

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- Mr. Max Weibicke of TU-Dresden shared insights and code for data processing
- Funding was provided by NSF grant CMMI-1853056, the Edward G. and John R. Cahill Chair, and the Berkeley-France Fund
- ENGEO Inc. provided undisturbed samples from Treasure Island