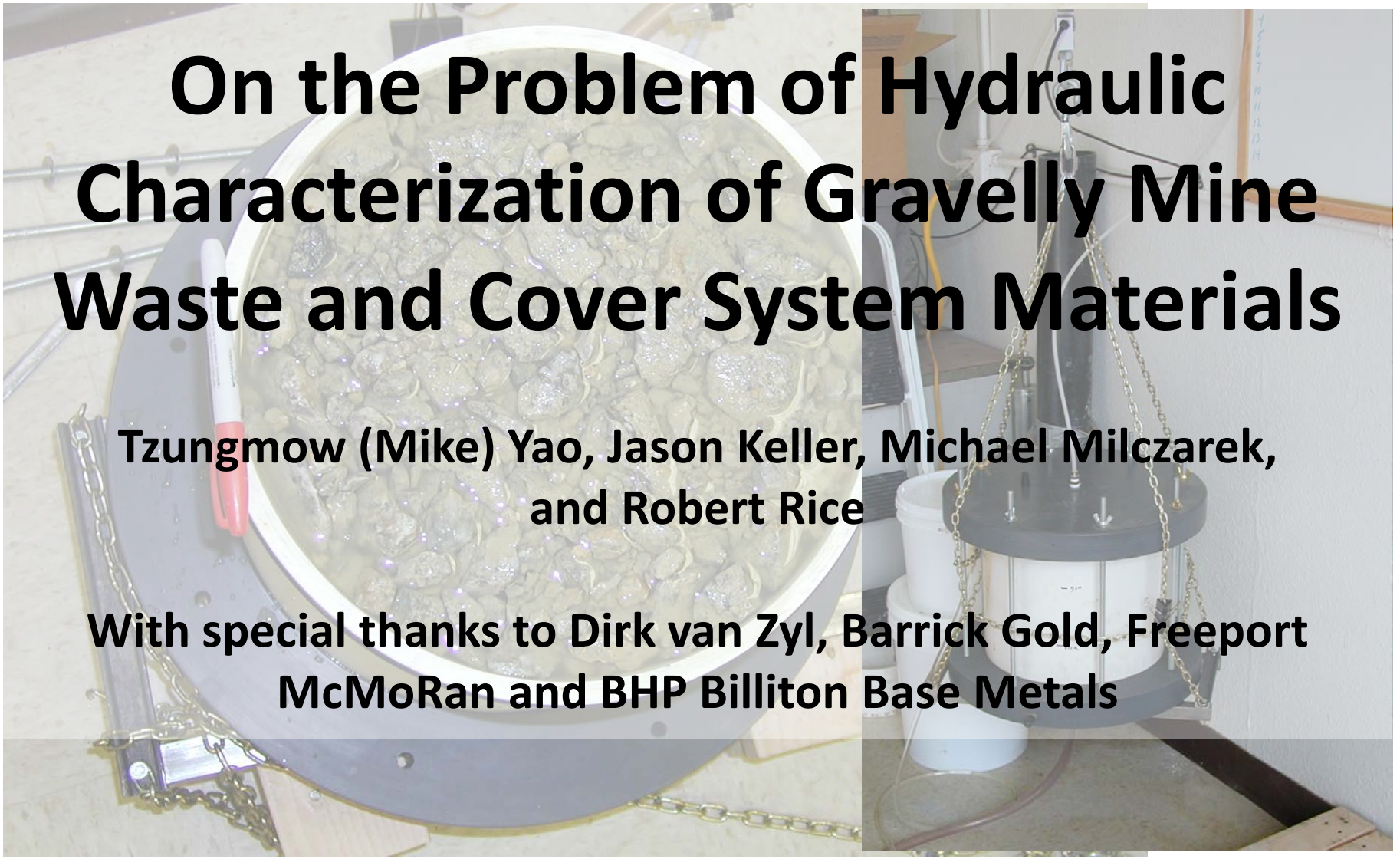

On the Problem of Hydraulic Characterization of Gravelly Mine Waste and Cover System Materials

Tzungmow (Mike) Yao, Jason Keller, Michael Milczarek, and Robert Rice

With special thanks to Dirk van Zyl, Barrick Gold, Freeport McMoRan and BHP Billiton Base Metals

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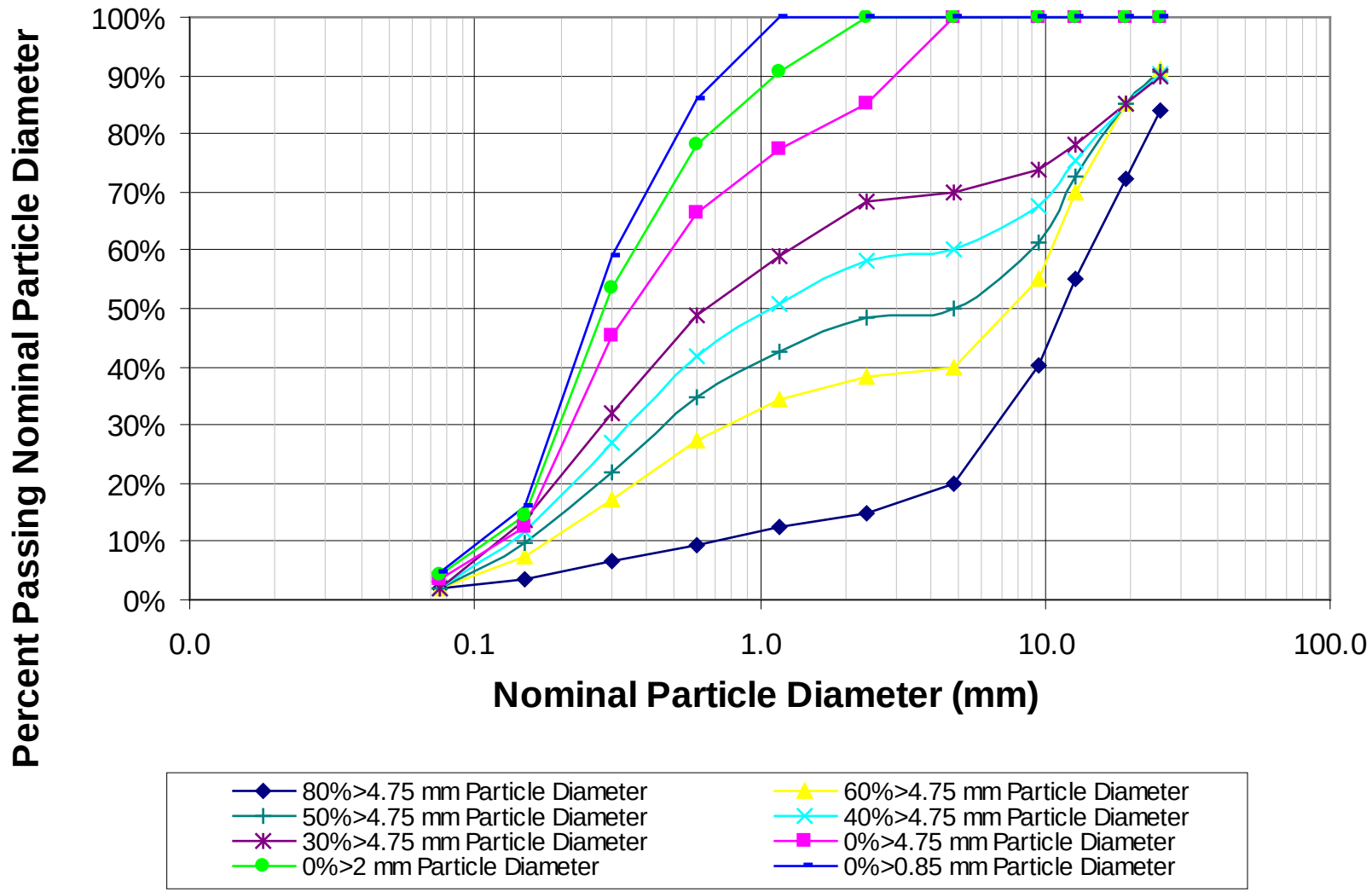
Background

- Mine materials have lots of rocks…….
- Presence of rock/gravel affects flow properties
  - Small amounts act as barriers to flow
  - Large amounts can create extra structure and pores = macropores or preferential flow
- Current laboratory methods not designed for gravelly materials
  - Based on agricultural or well engineered soils
  - Remove rocks from sample, then use correction factors
  - Crushed, angular, wide particle size distribution
  - Restacked with variable structure
  - Theoretical assumptions for data analysis can be invalid

Gravel Removal – how much?
Early work - Saturated conductivity study for gravelly soils

Gravel percentages and particle size for tested soils



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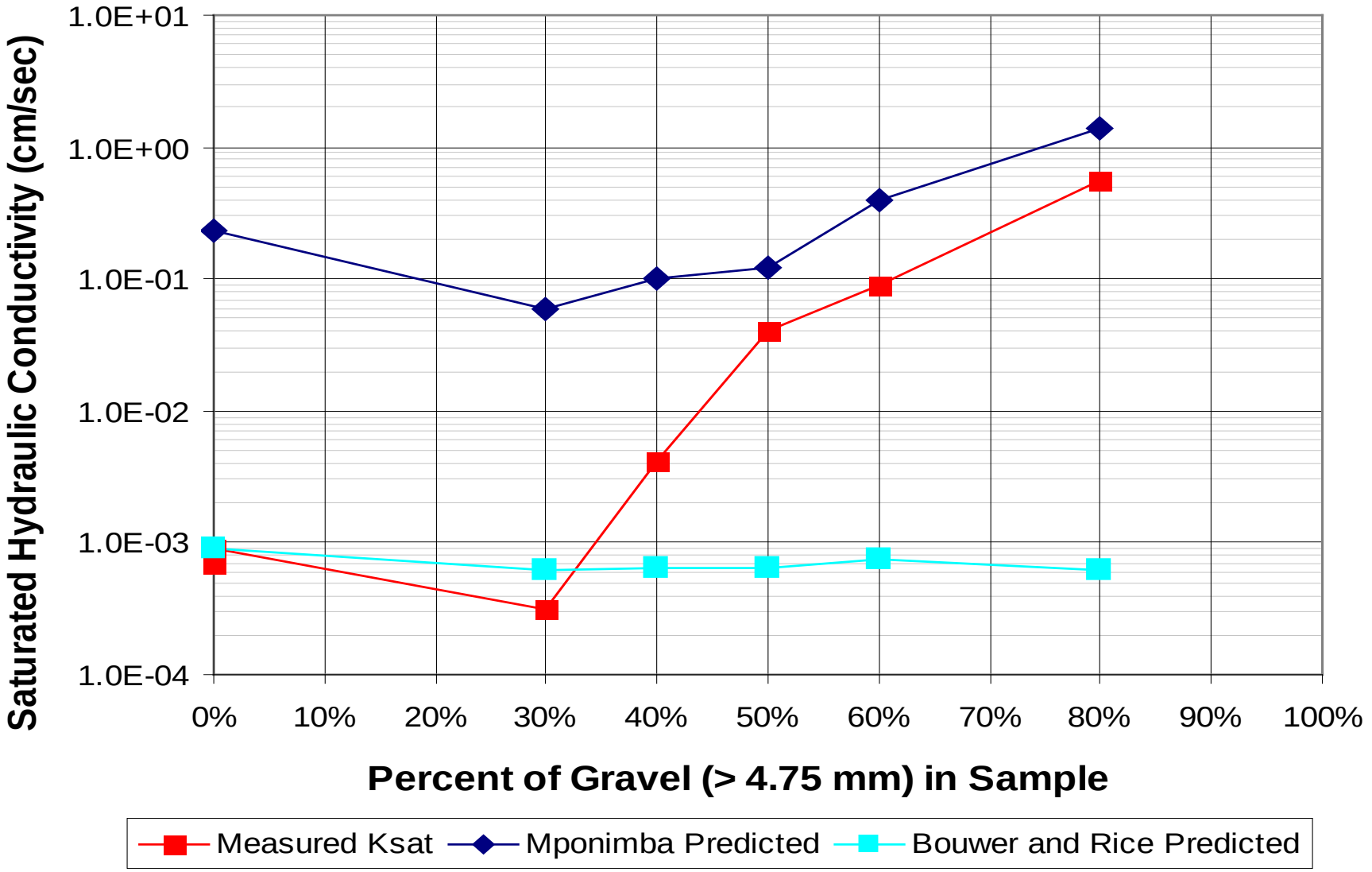
2” vs. 12” Ksat tests for gravel materials



Why is This Important?

- We build models to design for closure:
  - Estimate heap leach draindown
  - Estimate cover performance
  - Estimate water balances
- Consequences can be costly:
  - Oversize/undersize water treatment
  - Excess infiltration/deep percolation
  - Underpredict water holding capacity of waste
  - Underpredict drainage response to storm events
- Need representative, cost-effective methods to define unsaturated flow characteristics

Obstacles

- Accurate soil water retention measurements in gravelly samples are difficult
  - Near saturation, moderate and dry tensions need different measurement methods
  - Big changes in flow with small changes in water content at wet range
  - Extremely slow water movement in moderate tension to dry range (test could last for months to years)
- Cost and robustness
  - Large sample sizes needed for representativeness
  - Scaling of columns to larger systems

New Hydraulic Testing Methods

1. Review PSD data to determine the core diameter needed
   - Use core diameter 8X of largest particle diameter
   - Do not remove more than 20% of sample
2. Pack and instrument large diameter cores with water content and tensiometer sensors
3. Hydraulic property measurements to determine
   a. Saturated hydraulic conductivity
   b. Unsaturated hydraulic properties at range of probable infiltration rates (i.e. 10^{-3}, 10^{-4} and 10^{-5} cm/sec)
   c. Measure soil water retention characteristics
4. Flexible wall hydraulic property measurements
   a. Minimize edge effect between test material and rigid wall
   b. Different hydraulic tests at variable bulk densities in one flow column
   c. Obtain uniform compaction and minimize differential compaction

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Gravel material in 12” test cell

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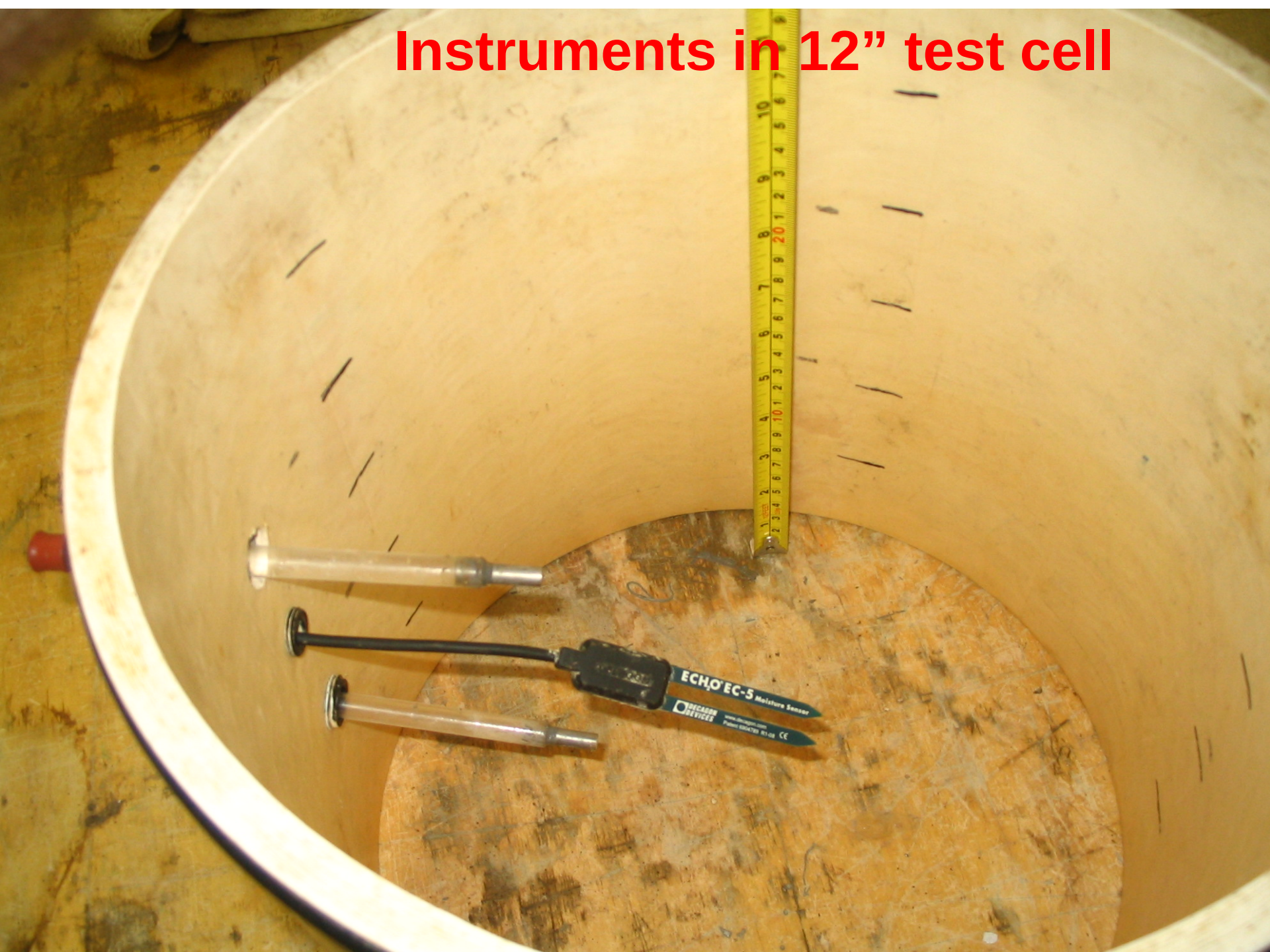
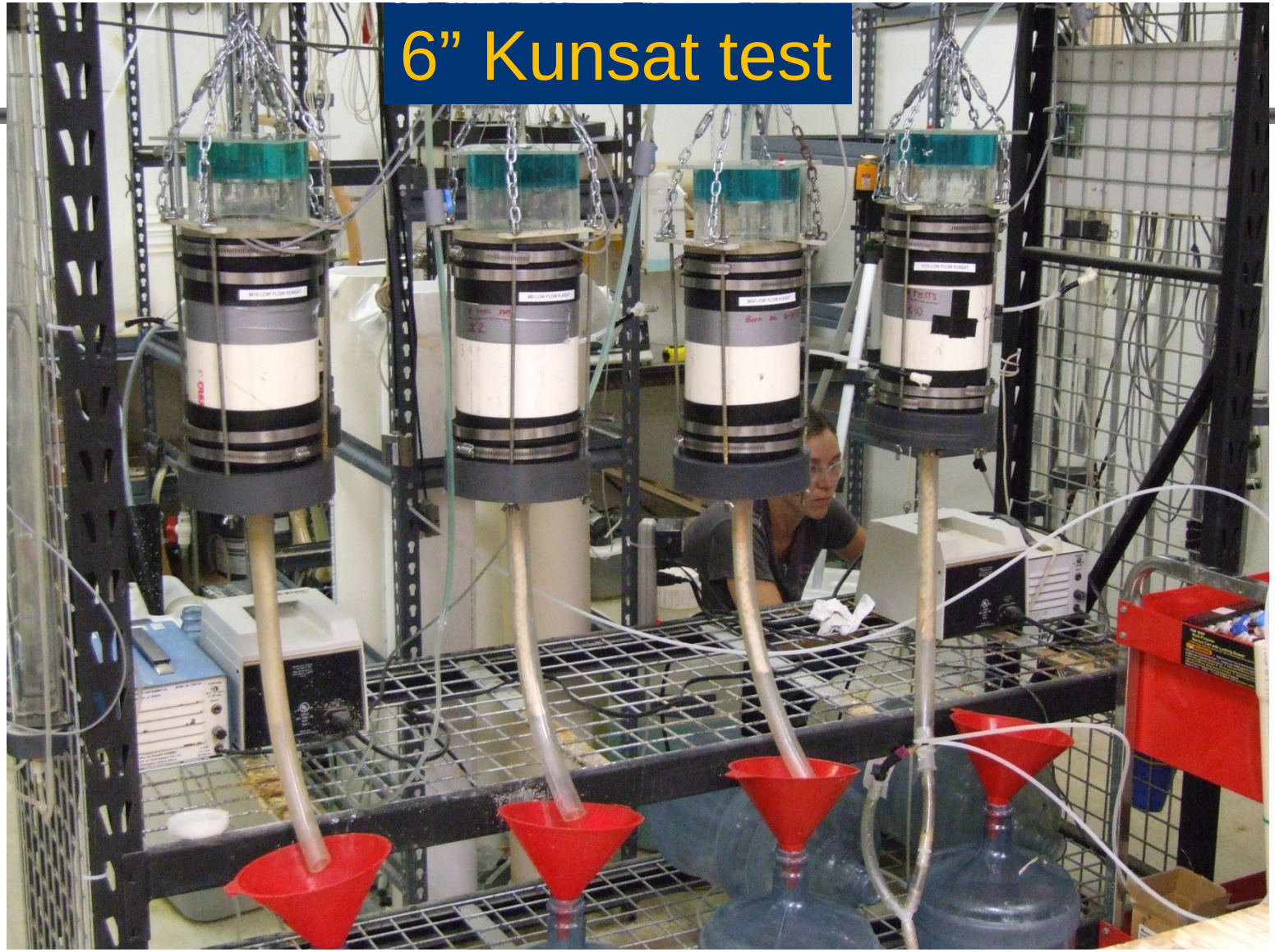
Instruments in 12” test cell



6” Kunsat test



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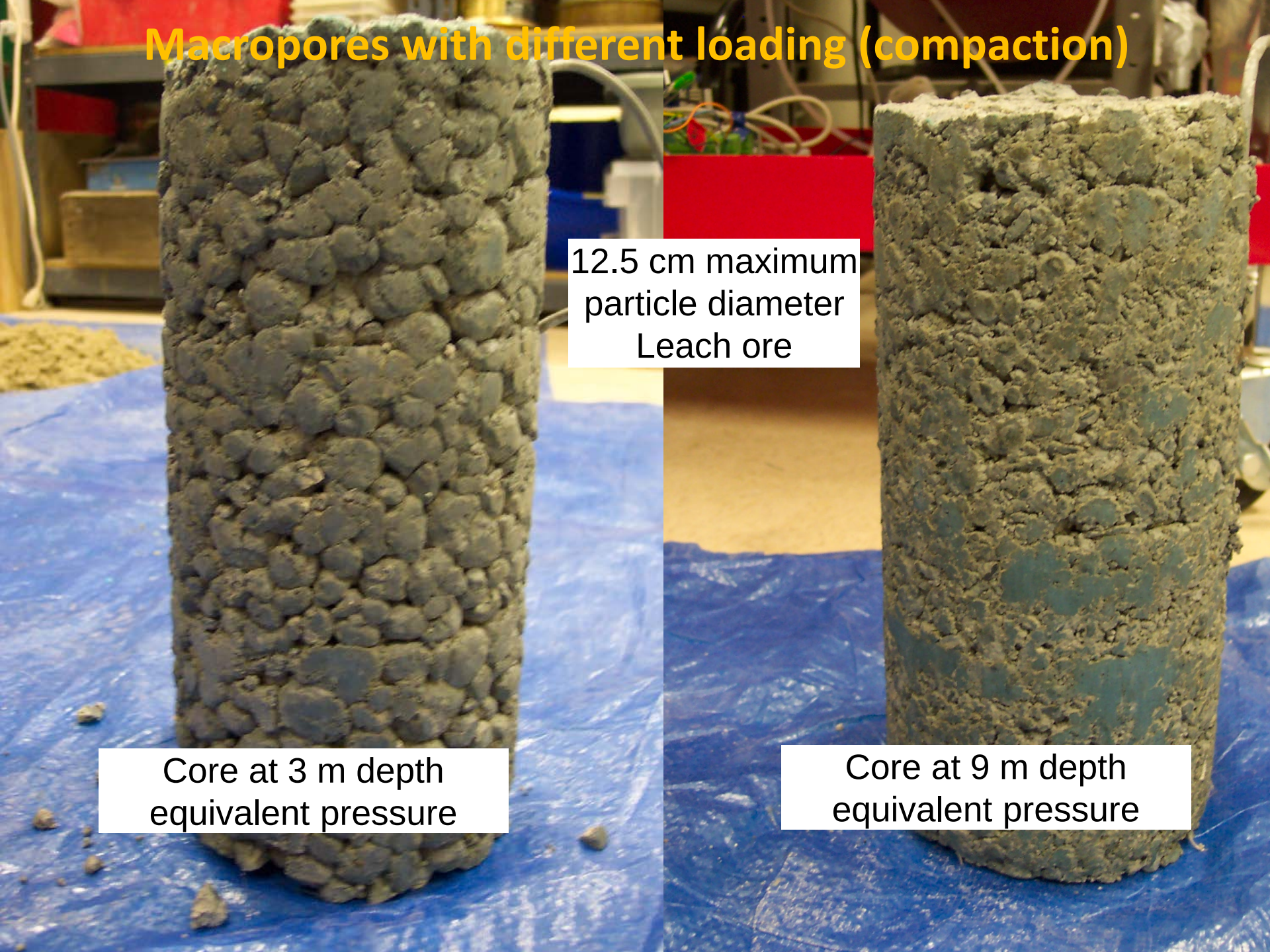
12” Kunsat test

12” Ksat test

Macropores with different loading (compaction)

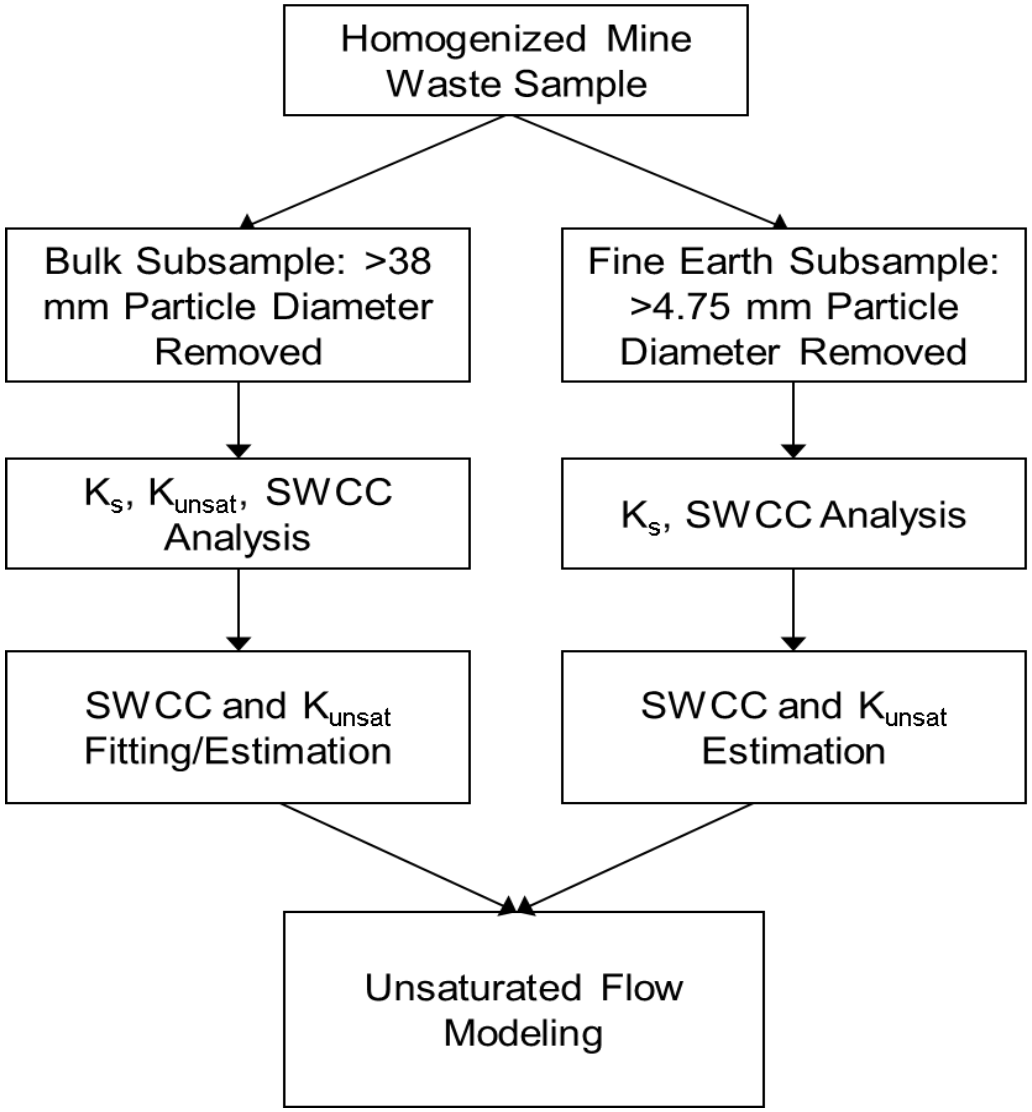


12.5 cm maximum particle diameter Leach ore

Core at 3 m depth equivalent pressure

Core at 9 m depth equivalent pressure

Case Study 1 – Rock Removal



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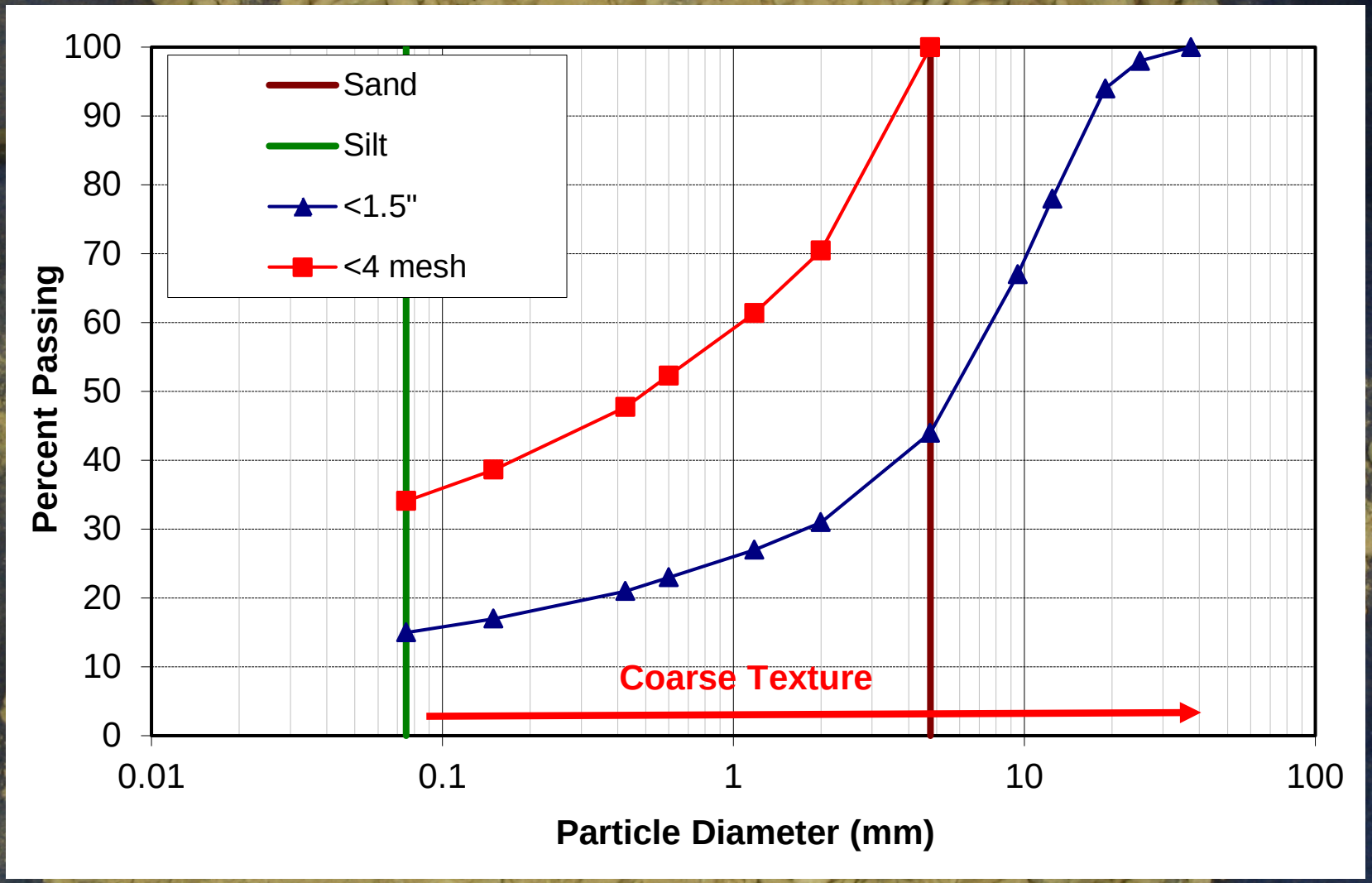
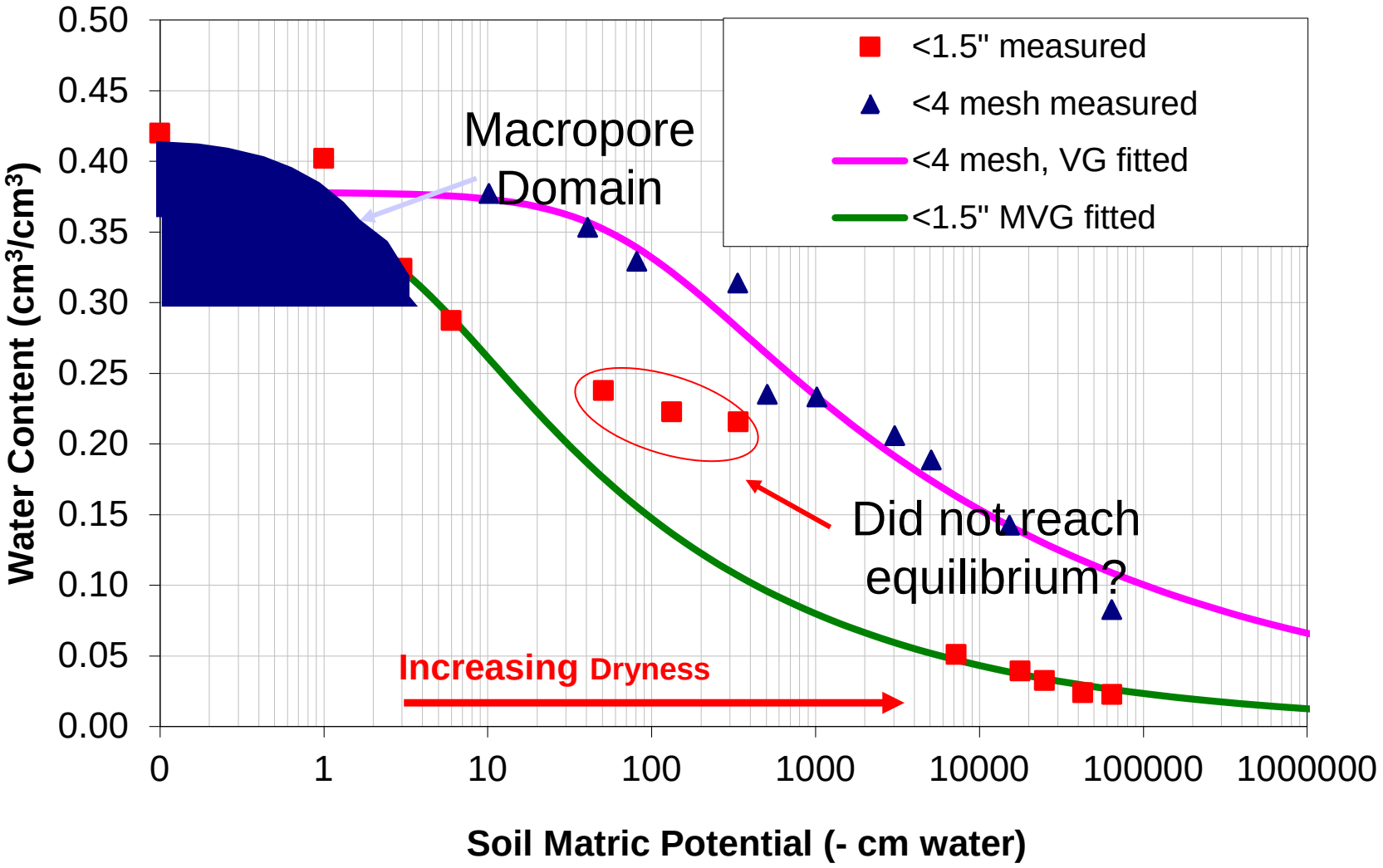
Case Study 1


Sand
Silt
<1.5"
<4 mesh
Percent Passing
100
90
80
70
60
50
40
30
20
10
0
0.01
0.1
1
10
100
Particle Diameter (mm)
Coarse Texture

Soil Water Retention Characteristics



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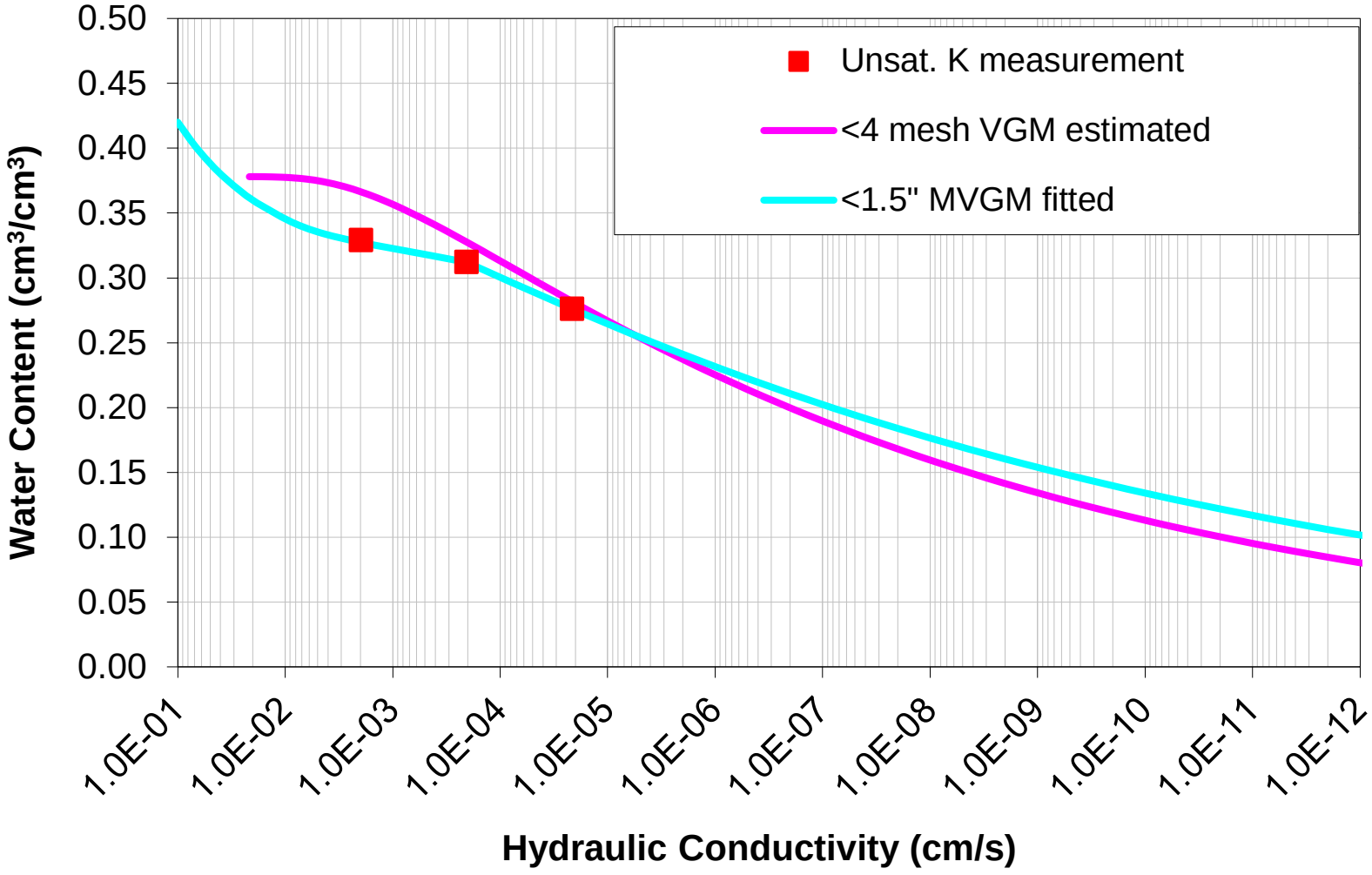
Hydraulic Conductivity



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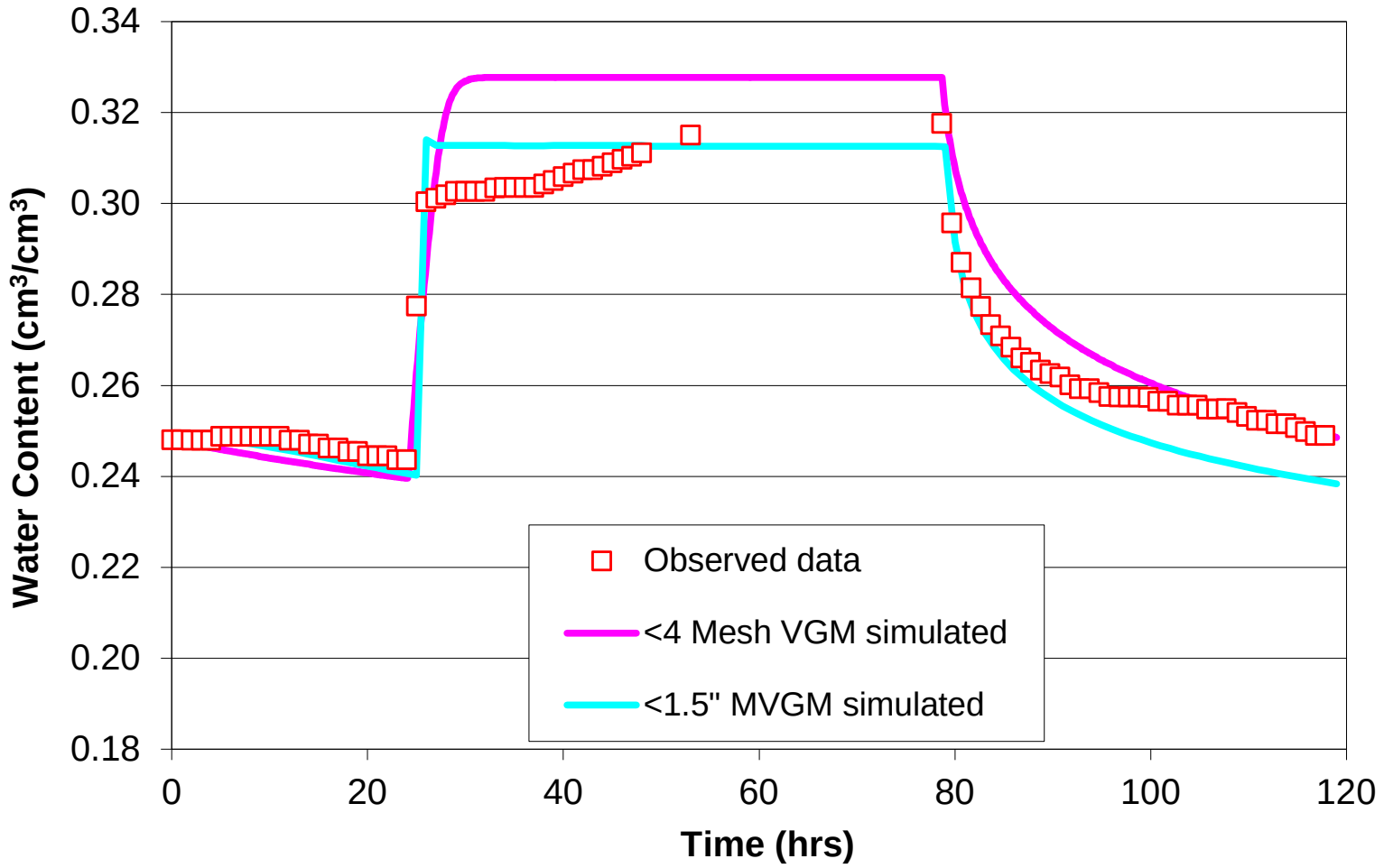
Simulated Water Content



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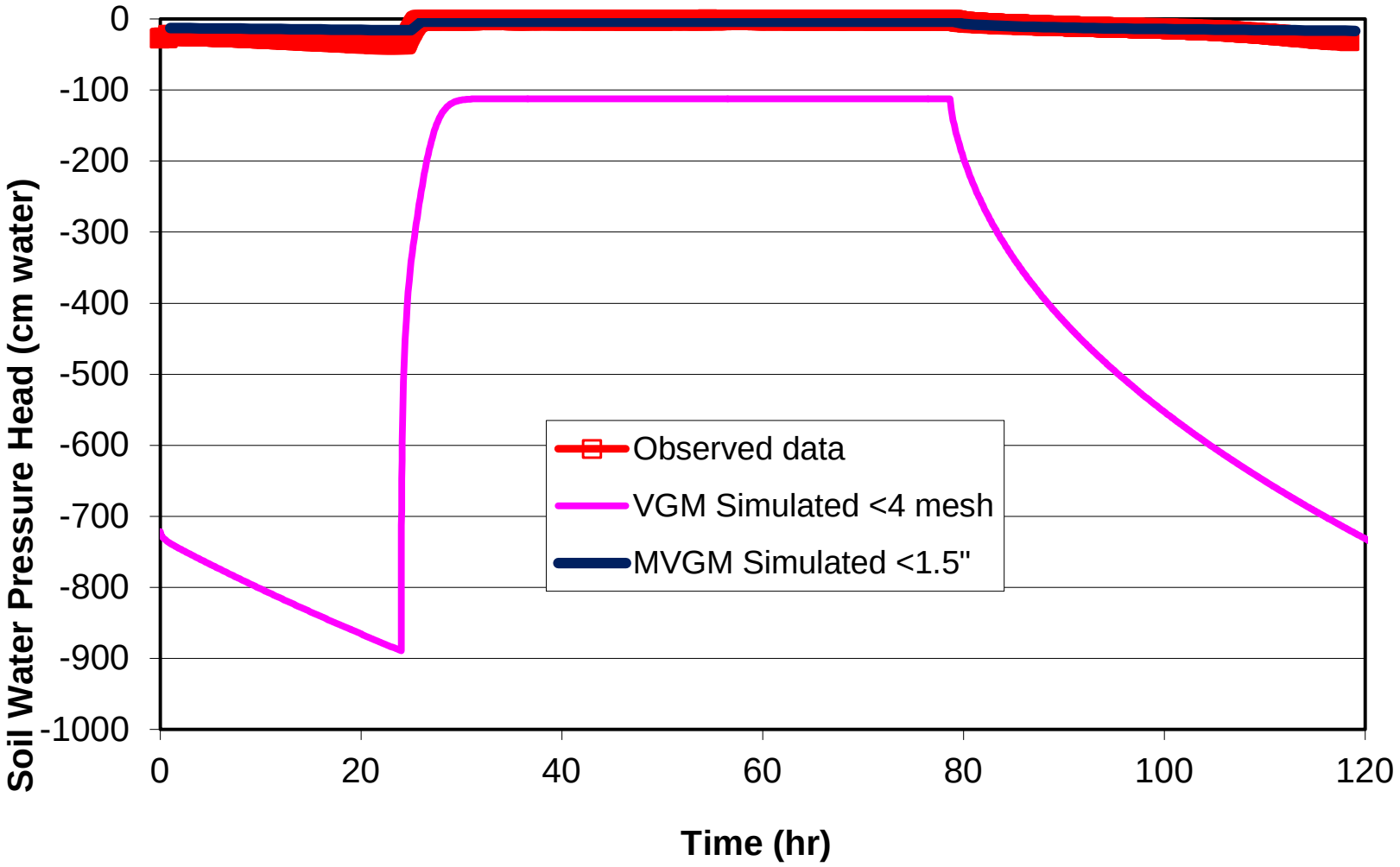
Simulated Pressure Head



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Lessons Learned from Case 1

- Parameters derived from gravel removed fine soils can not represent the original soil hydraulic properties
- Two domain (permeability) model is needed to best fit the measured data
- Direct Kunsat measurement can greatly stabilize the fitted parameters and generate better results than predicted parameters

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Case Study 2 - Flexible Wall Hydraulic Measurements

- Two different leach ores (coarse and finer-grained)
- Consolidation permeability tests to determine
  - Bulk density at different overburden pressures
  - Solution and air permeability at different overburden pressures

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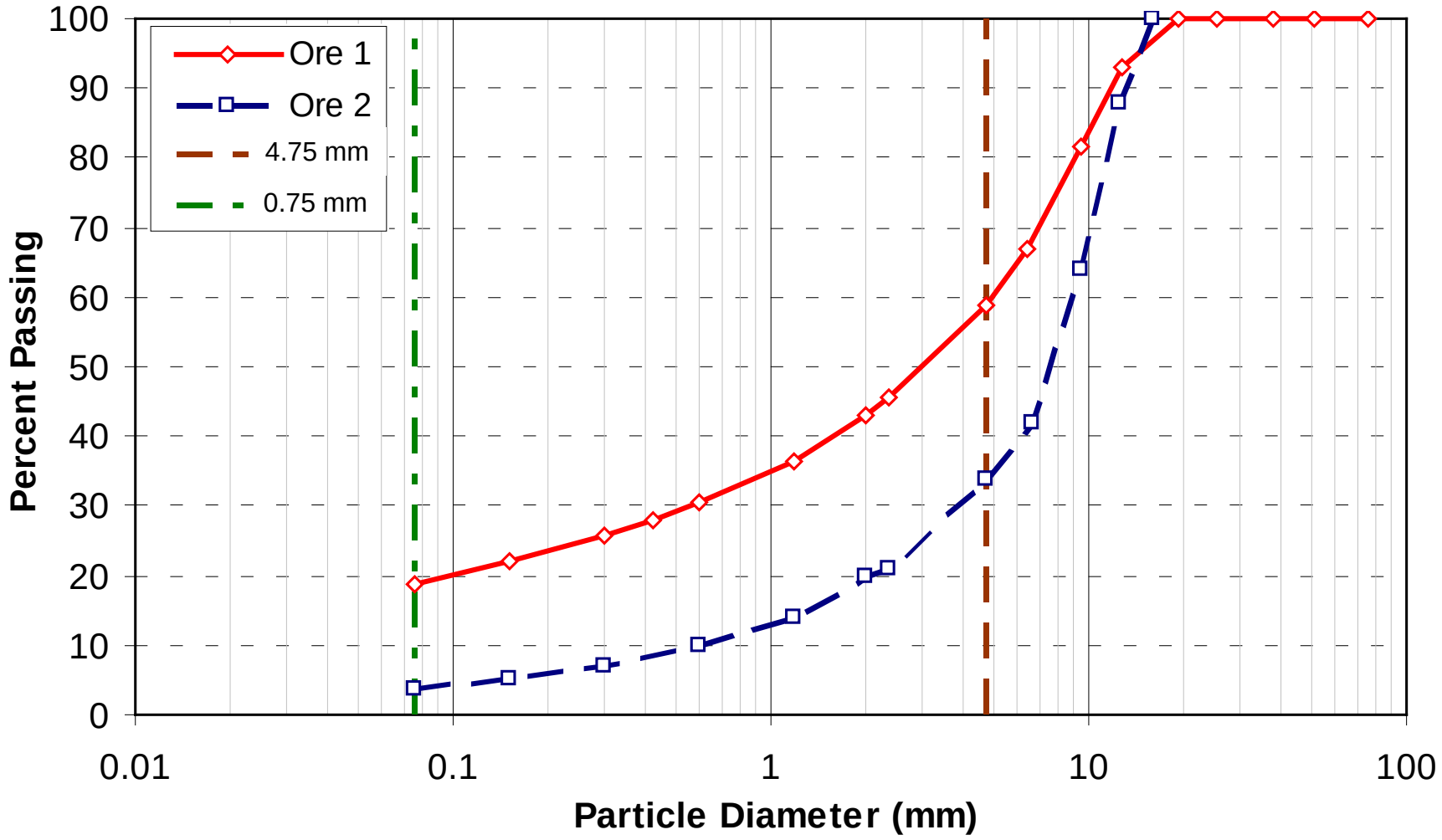
Sample Particle Size Distribution



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Leach Ore 1

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Leach Ore 2

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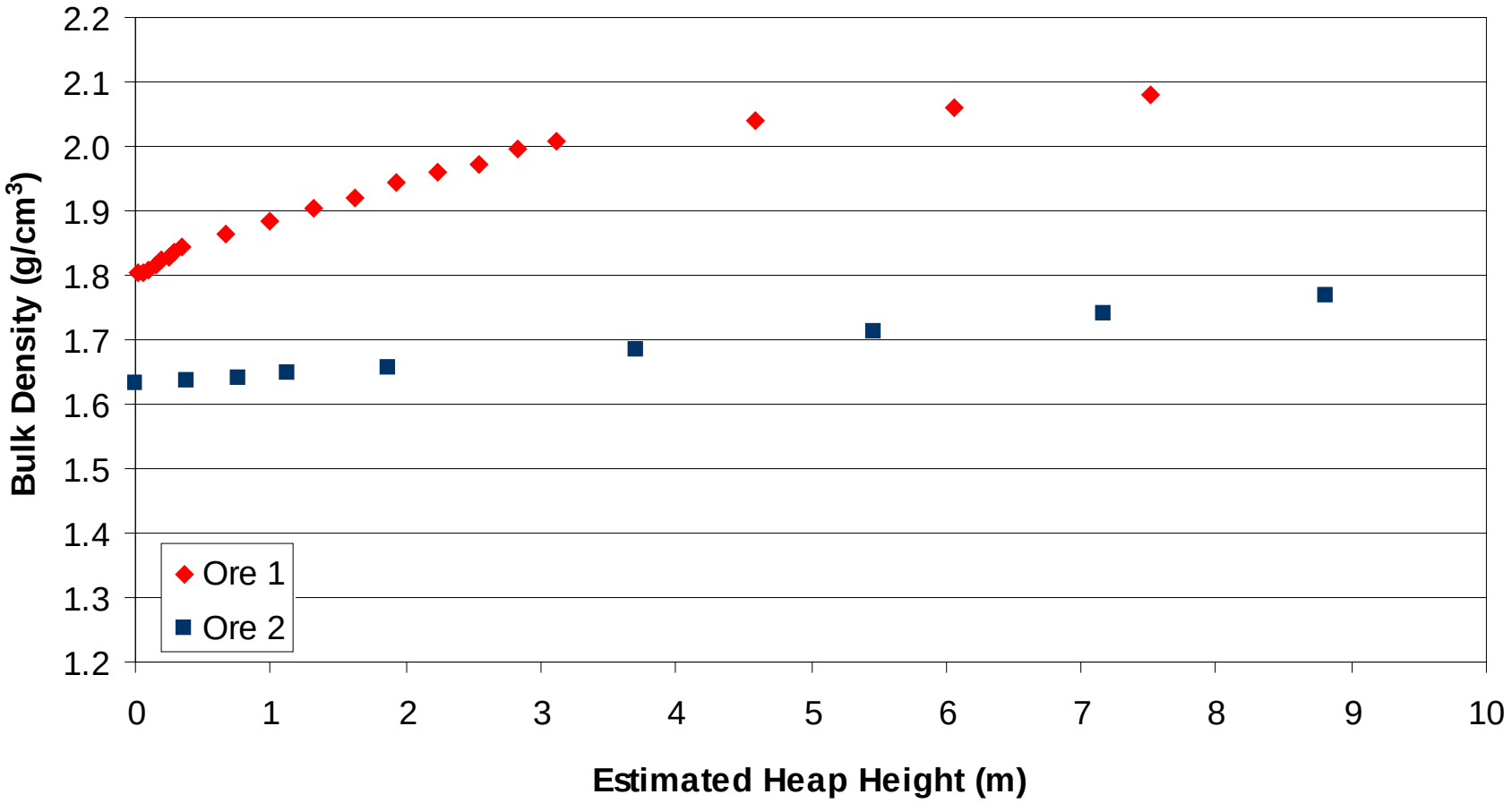
Bulk Density vs Heap Height



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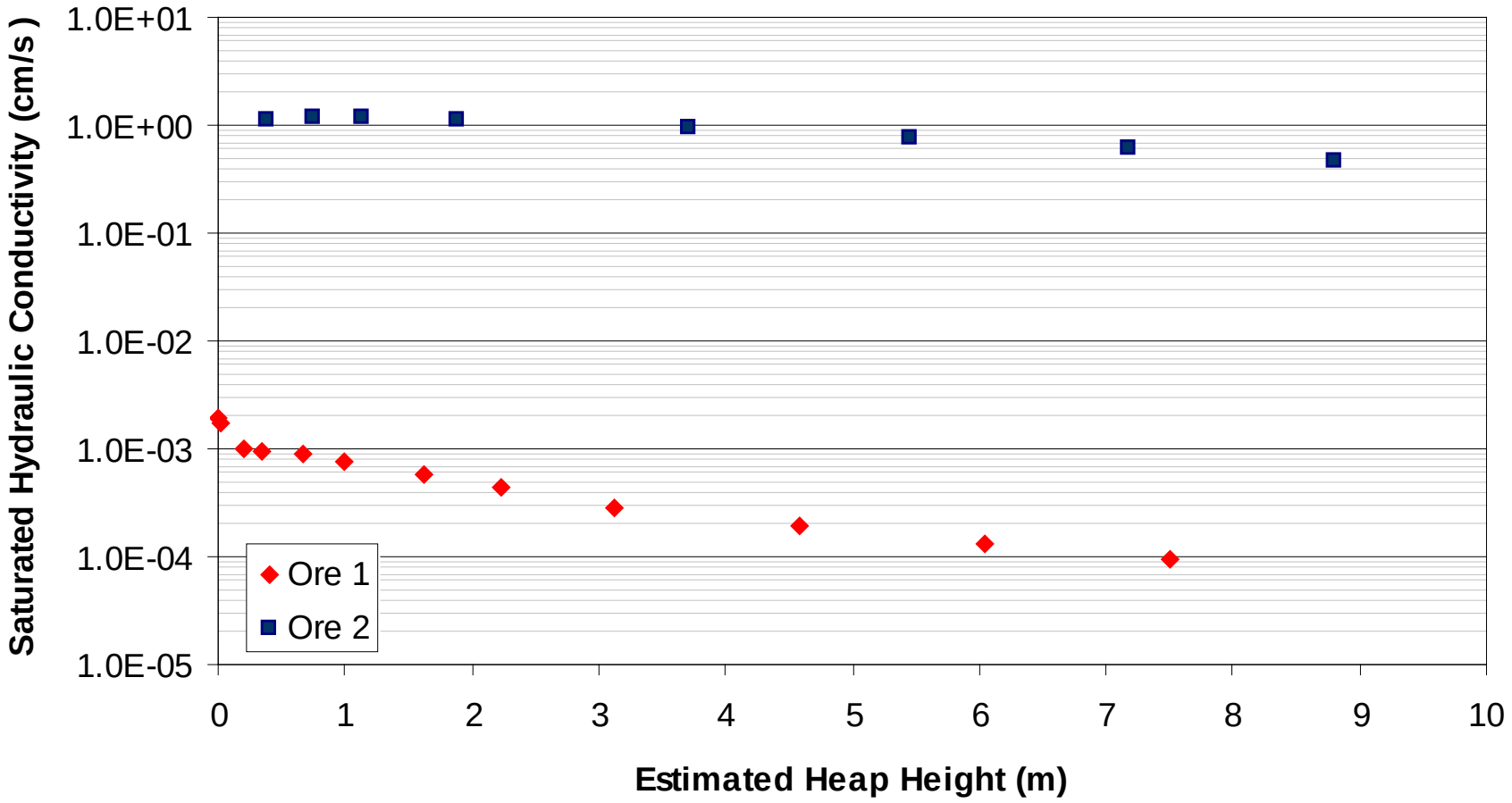
Ksat vs Heap Height



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Conclusions

- Removing gravel and determining hydraulic properties on 2-inch cores:
  - Does not scale to larger sample sizes
  - Can lead to gross errors and significantly deficient models of gravelly materials
- New laboratory methods appear to:
  - Significantly improve our ability to forward model
  - Increase test efficiency for variable sample density
  - Reduce the possible effect of macropore flow
  - Improve parameters accuracy with direct Kunsat
- More research needed to:
  - Define when matrix flow ends and macropore begins
  - Model macropore systems

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Thank You
Papers available upon request
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