$10 Million Tuff "Pods" in the Dam Foundation

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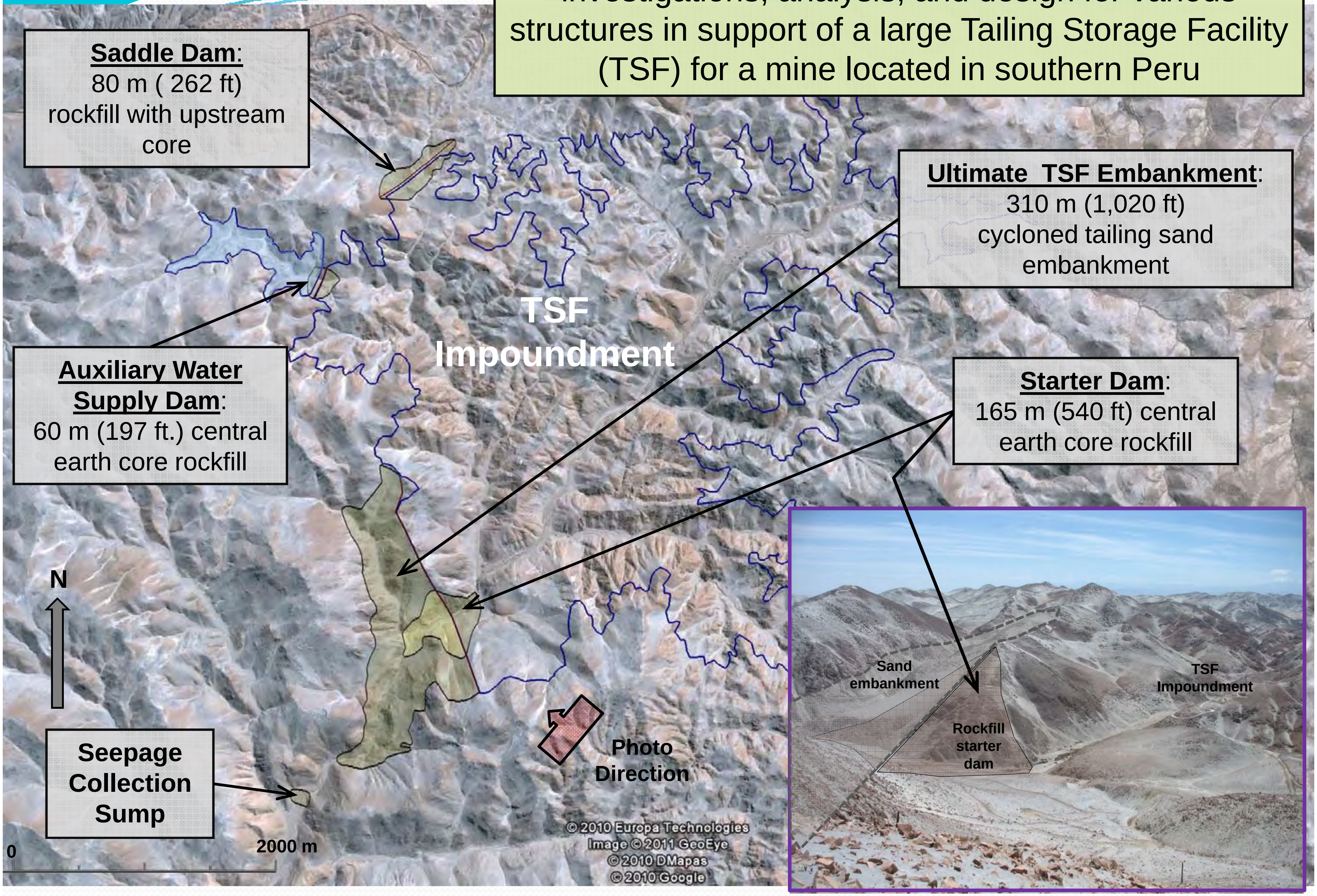
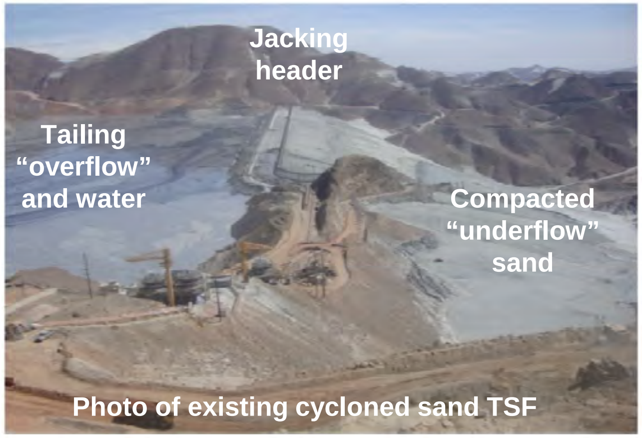
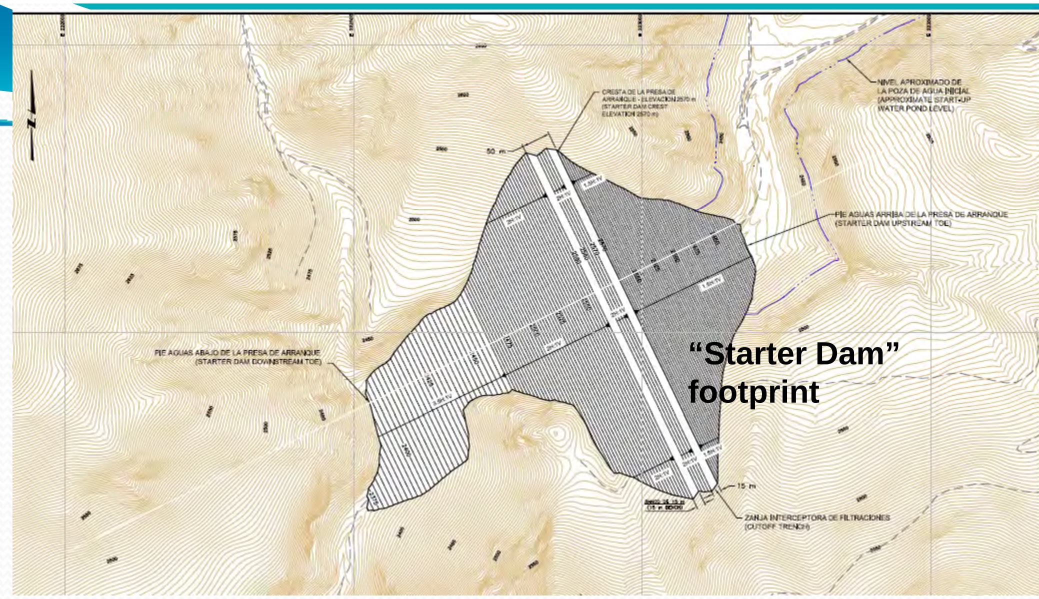
Project Scope

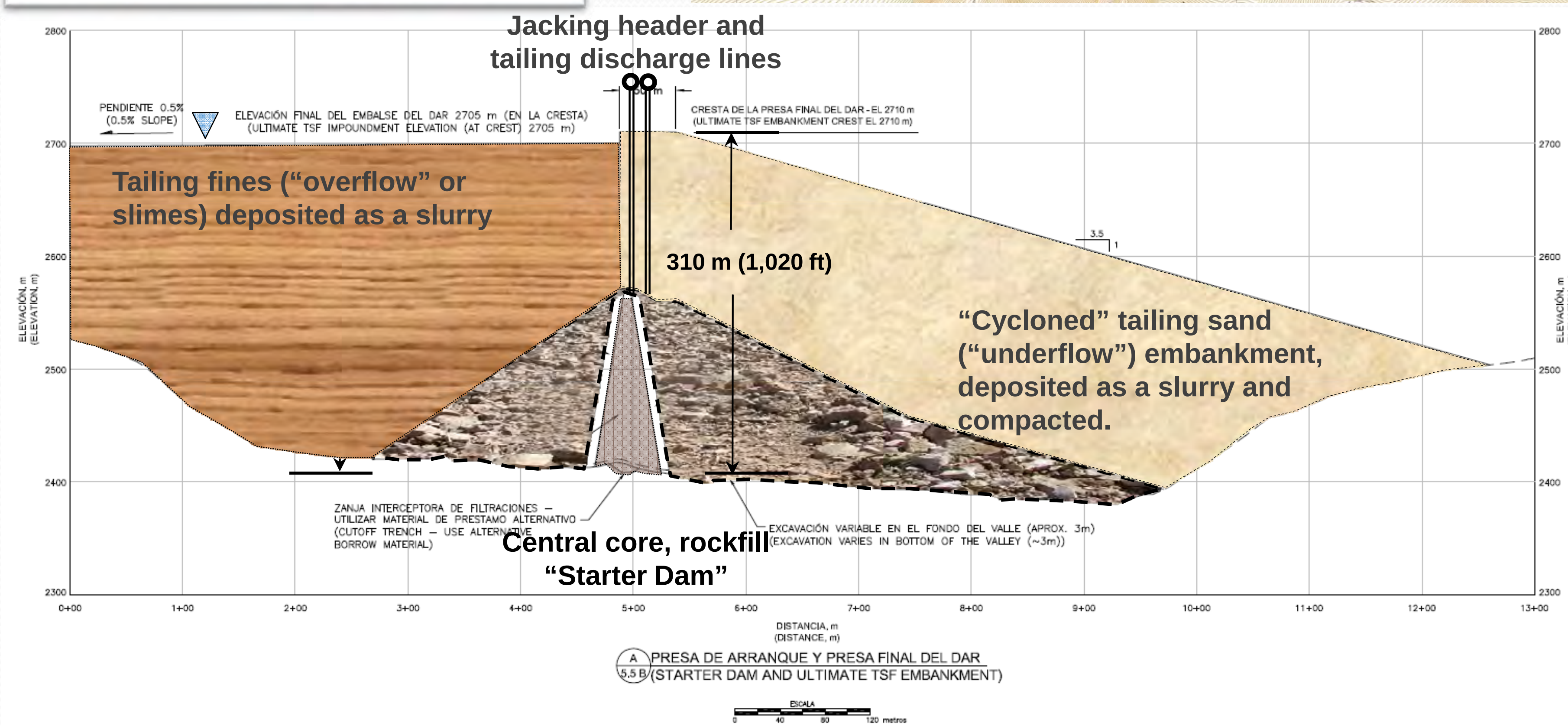
MWH is currently providing final engineering investigations, analysis, and design for various structures in support of a large Tailing Storage Facility (TSF) for a mine located in southern Peru



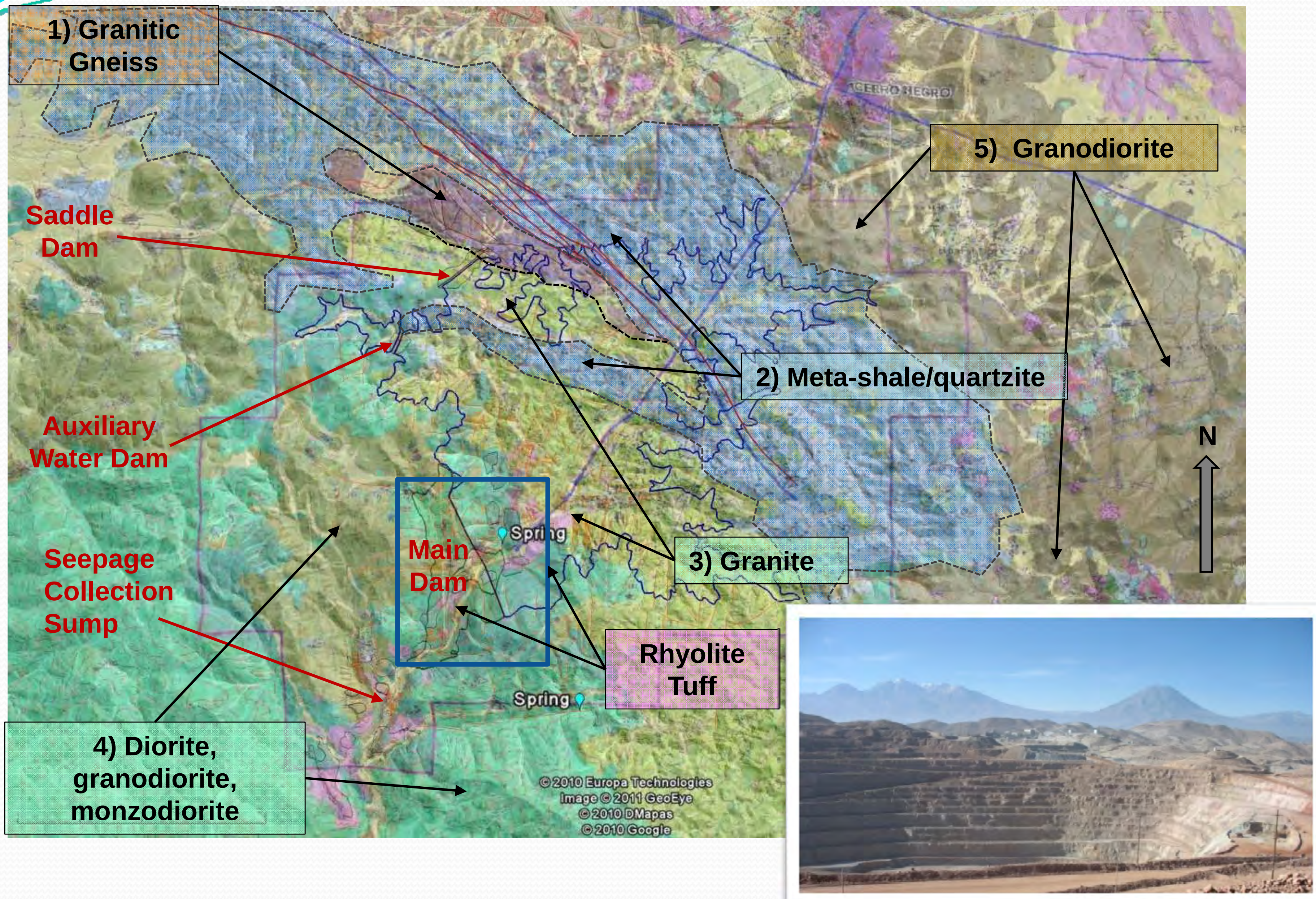
TSF Configuration



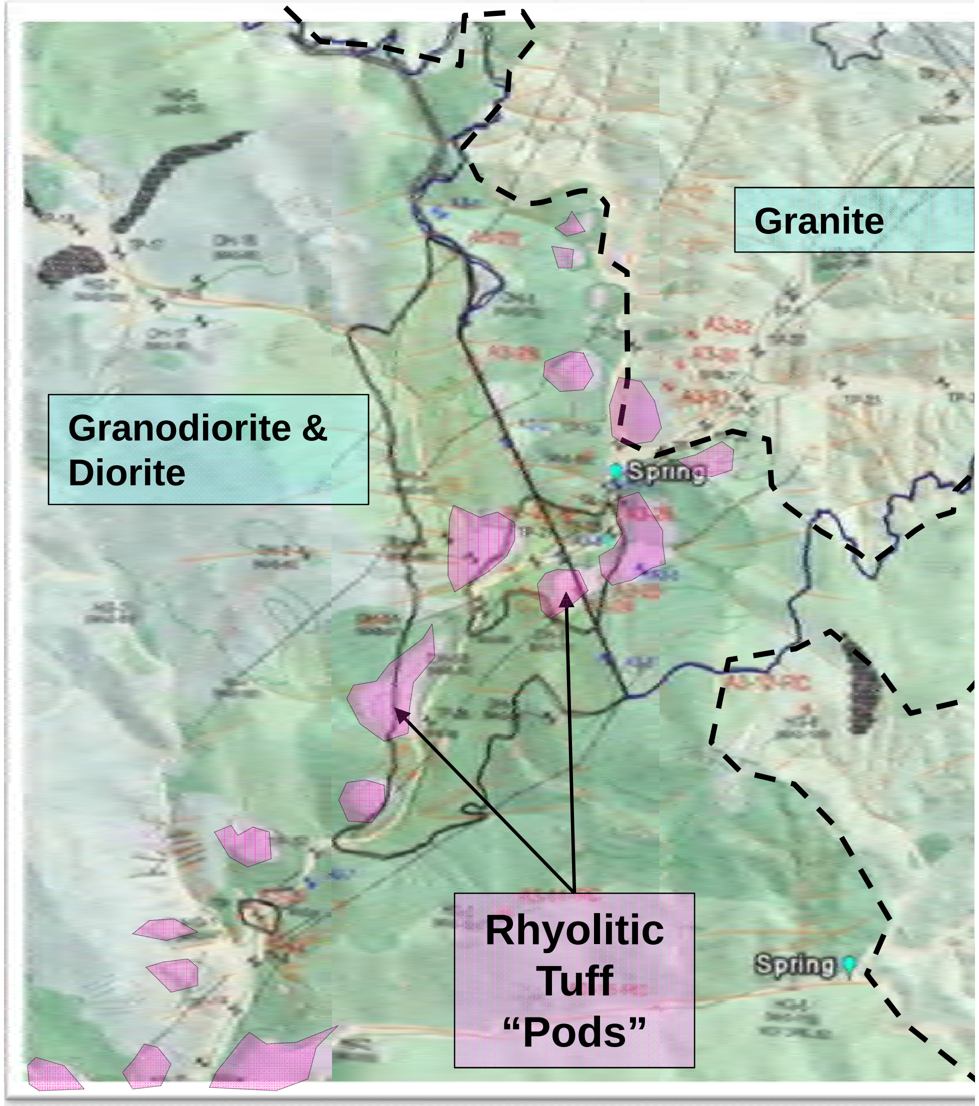




Project Geologic Setting



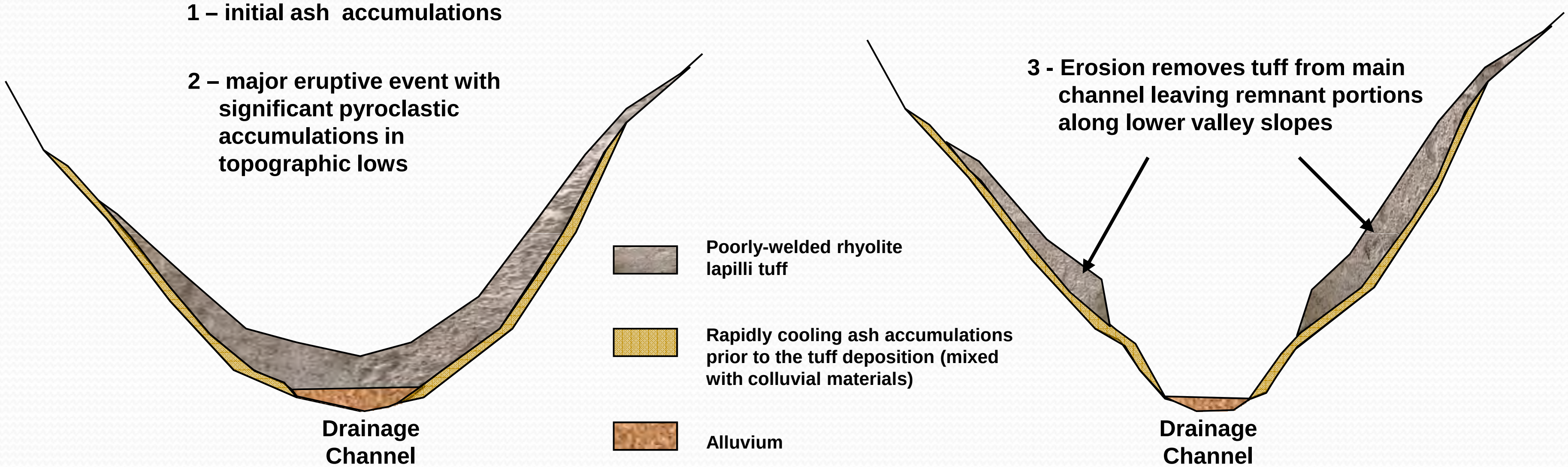
Geologic Site Conditions – Main Dam



Site Conditions:

- ❑ **Fractured granodiorite and diortie intrusive bedrock across the majority of the proposed foundation and most of the impoundment.**
  - **Generally high quality foundation conditions and permeability that improves with depth.**
  - **Faults/shears, hydrothermal alteration, and/or fracture zones in the main dam area and seepage collection sump.**
- ❑ **Spring near the upstream foundation toe (related to K contrast b/t Granite and Diorite).**
- ❑ **Gypsum infilling of fractures within the rock mass.**
- ❑ **Rhyolitic Tuff "Pods" in the Starter dam and ultimate TSF Embankment footprint.**

Rhyolitic Tuff Deposition



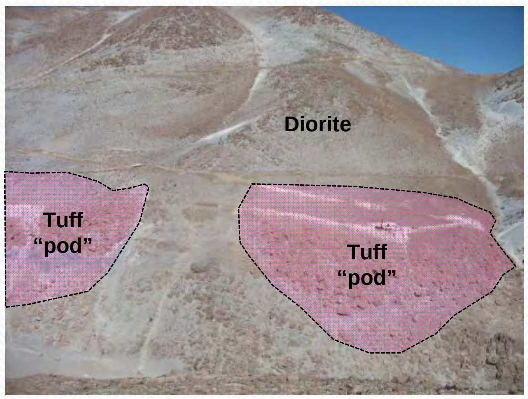
1 – Initially, ash accumulated in the in stream channels, swales, and on top of paleo-soil deposits and cooled quickly (may have been followed by a period of quiescence).

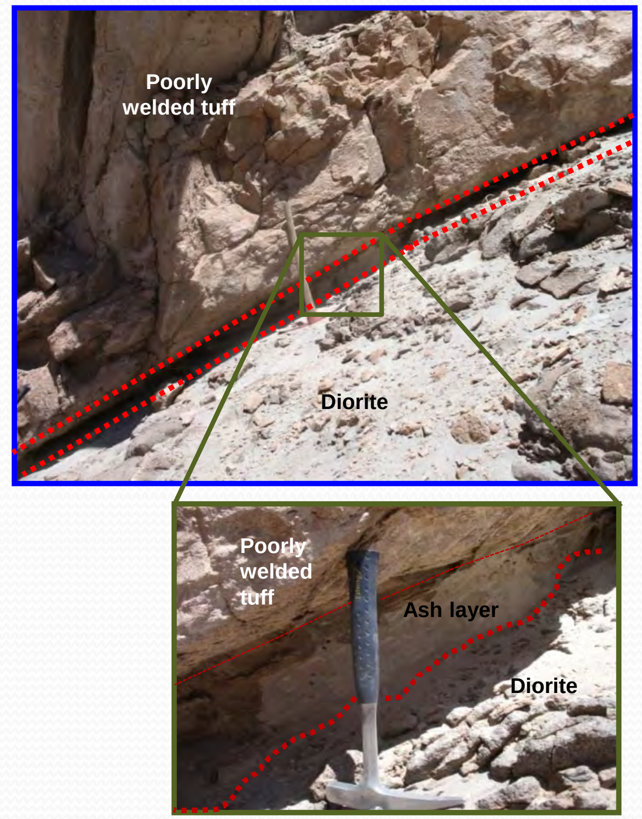
2 – Significant eruptive event resulted in thick pyroclastic accumulations (poorly welded tuff) along the stream channels, swales, and on top of the ash and/or paleo-soil deposits.

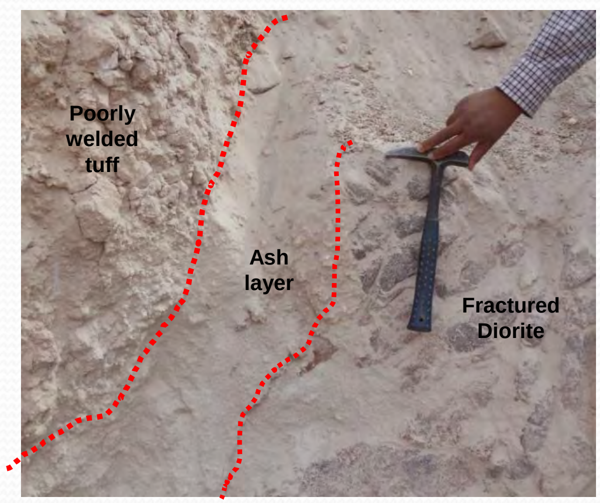
3 – Erosion removed the rhyolite tuff along the main stream channels resulting in discontinuous "*pods*" of this material left in place along the flanks of the valley slopes.

Feasibility Level Field Investigations

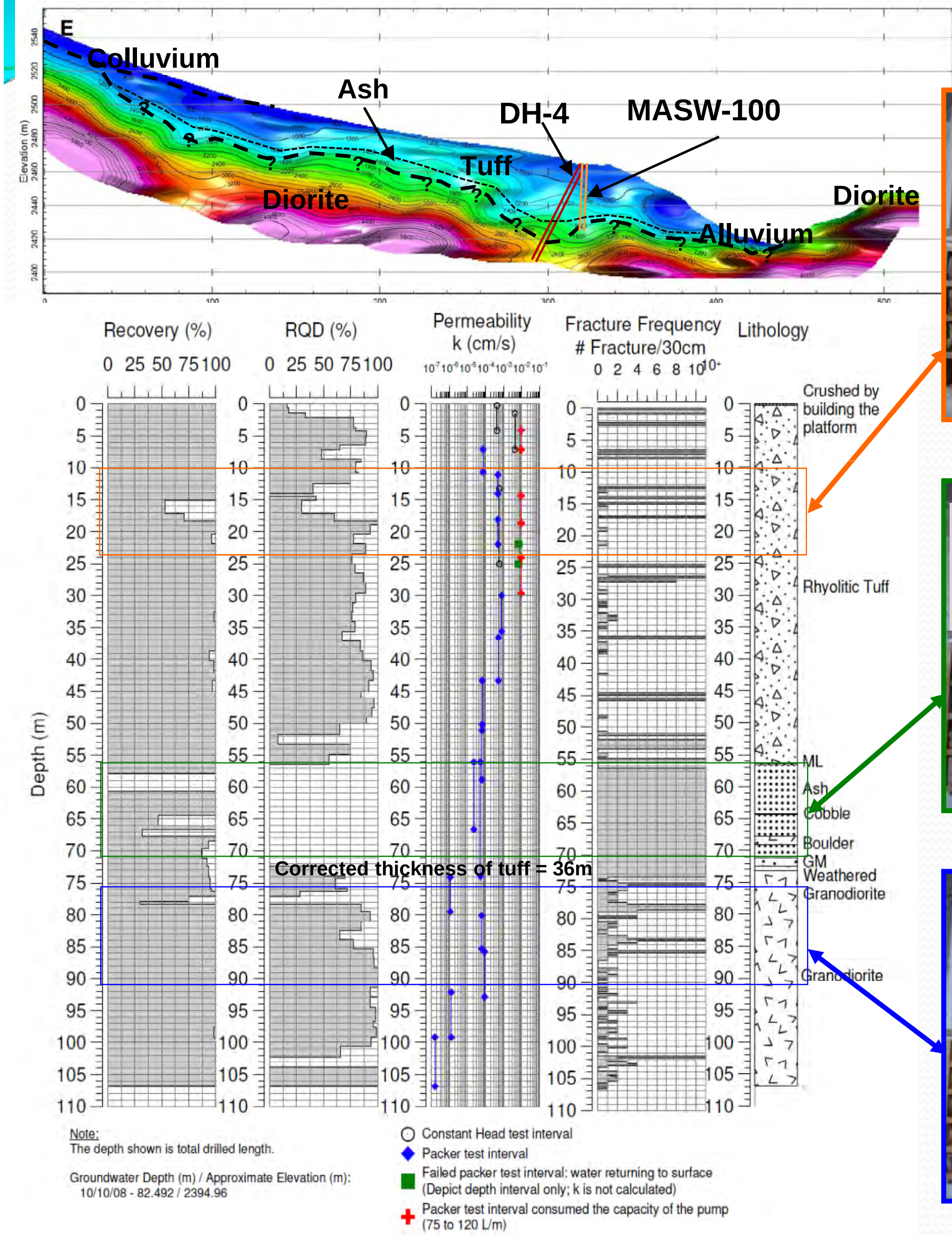
- Identification and detailed mapping of the spatial extent of the “pods”.
- Test pits excavated around the tuff “pod” perimeters
- One (angled) drill hole to understand the geometry and engineering conditions of the “pods”





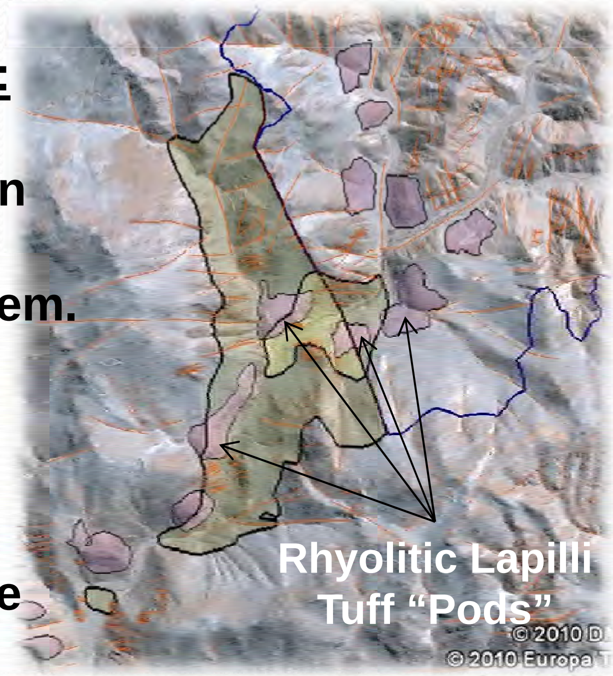


Feasibility Level Field Investigations



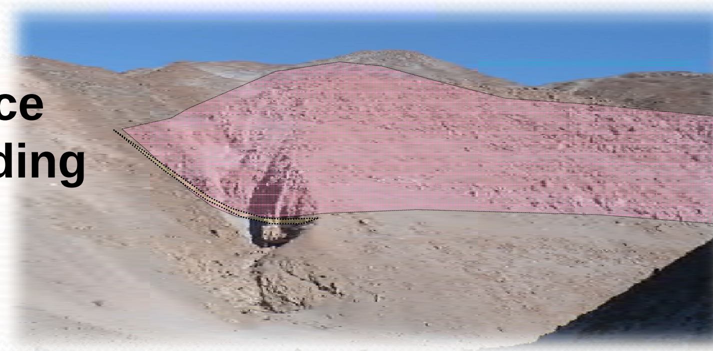
Technical Considerations/Constraints

- **Potential seepage pathway through or under "pods":**
  - **Pods are discontinuous U/S–D/S, however:**
    - **Irregular seepage gradients in the foundation**
    - **Piping of the underlying ash layer, or**
    - **Contamination/plugging of under-drain system.**



- **Potential liquefaction at base:**
  - **The underlying, fine grained silty sand (SM) ash could potentially liquefy under seismic loading resulting in settlement or deformations under the dam.**

- **Potential slope instability:**
  - **Ash layer could represent a basal slip surface and stability issues may develop due to loading and saturating of basal contact.**



- **Potential collapse or differential settlement:**
  - **Uncertainty about the ash response due to loading and saturation (i.e. collapsibility of air-fall type deposits)**

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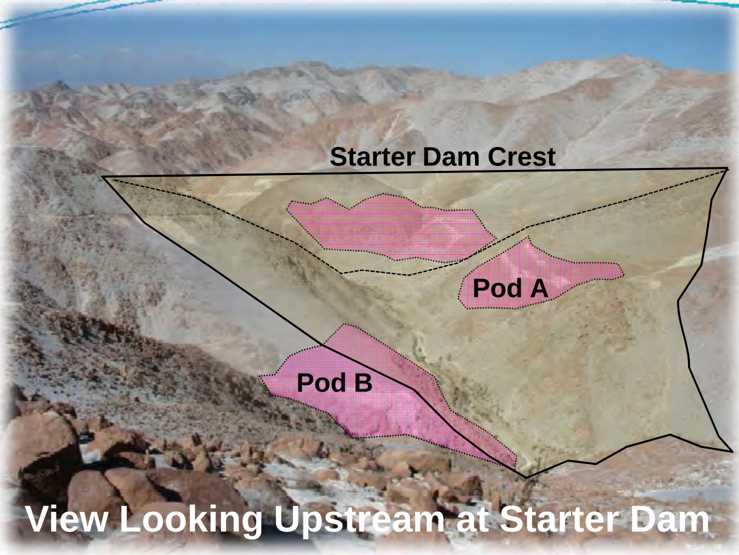
Estimated Removal Costs

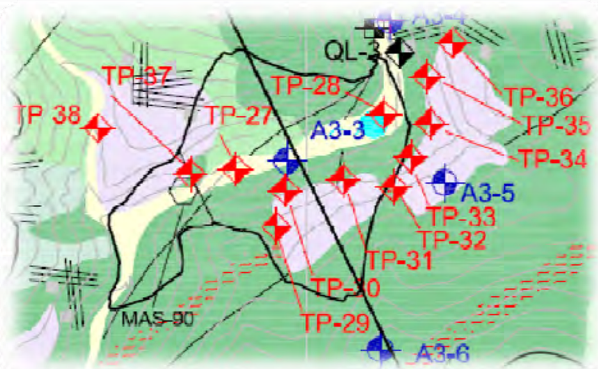


- Very costly to fully remove the pods
- Material is not useable (i.e. weak, low def. modulus, porous, unacceptable for rockfill, aggregate, or filters)
- Limited space for additional disposal
- Significant delays relating to construction schedule
- **Is it possible to leave all or partial tuff pods in place under the TSF Embankment?**

The extent, geometry, and engineering properties of the rhyolite tuff and ash must be characterized in the pods located in the area of the Main Dam.

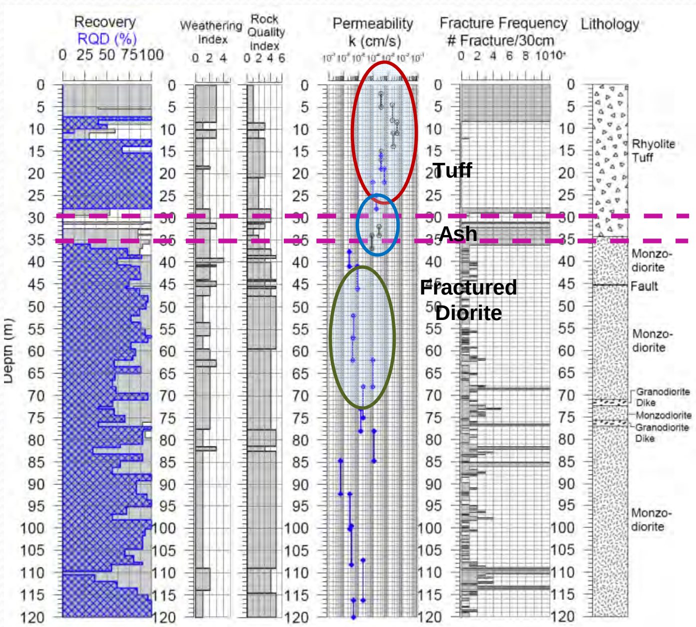
Final Design Level
Field Investigations

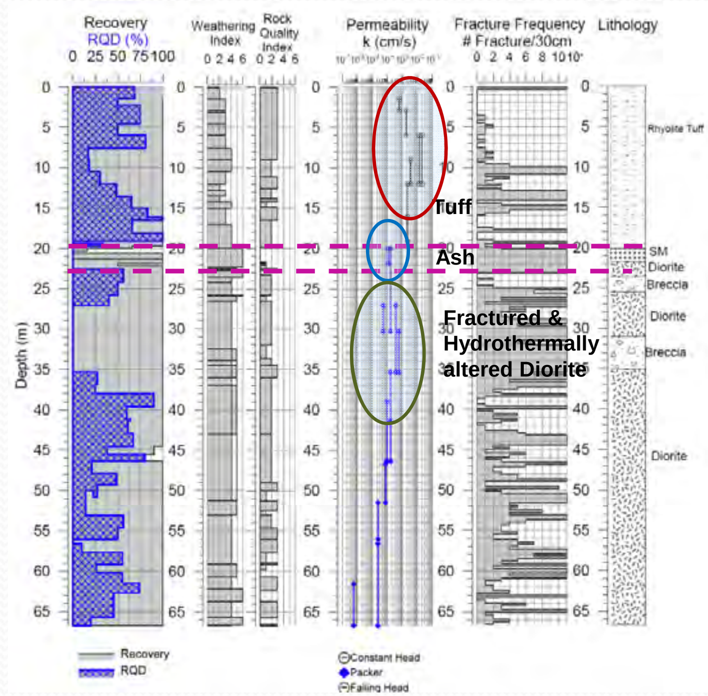
- Additional drilling
  - HQ core
- In-situ testing
  - SPT, MC, water pressure testing
- Test pits
  - sand cones
- Geophysics
  - refraction, MASW
- Lab testing
  - strength, consolidation, index properties, XRD



Drill Data

- **Tuff**: 2.5x10^{-3} cm/sec (high)
- **Basal ash** layer: 1x10^{-4} cm/sec
- Underlying upper **fractured diorite** (to about 5 m): 5x10^{-4} in near surface, highly fracture zones.





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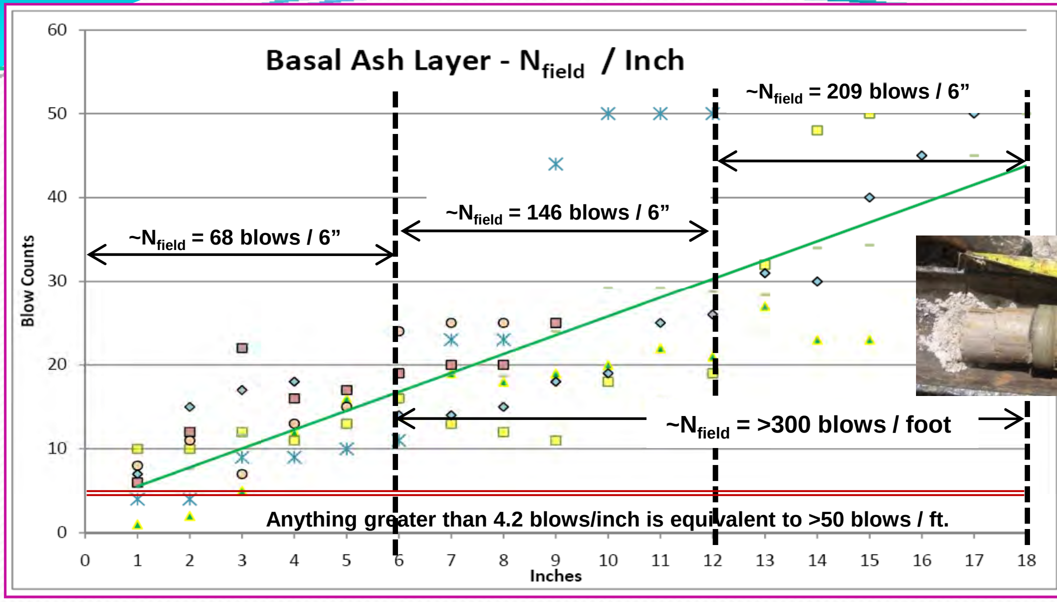
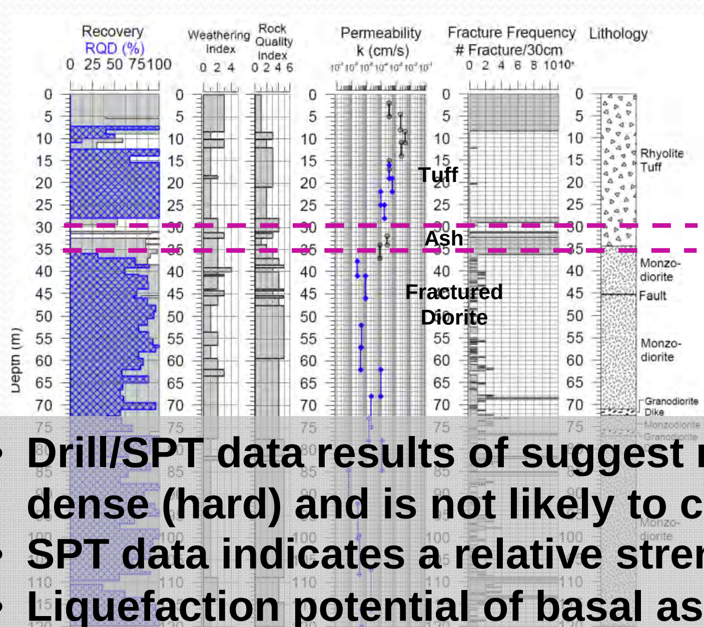
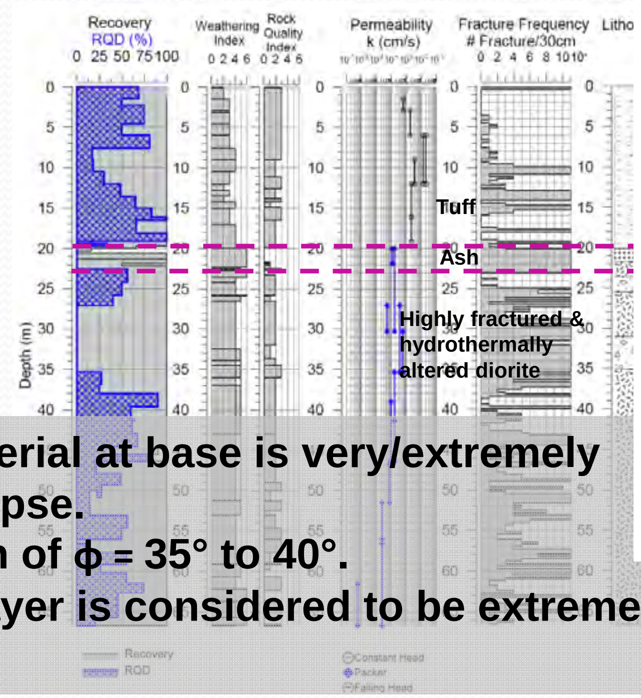
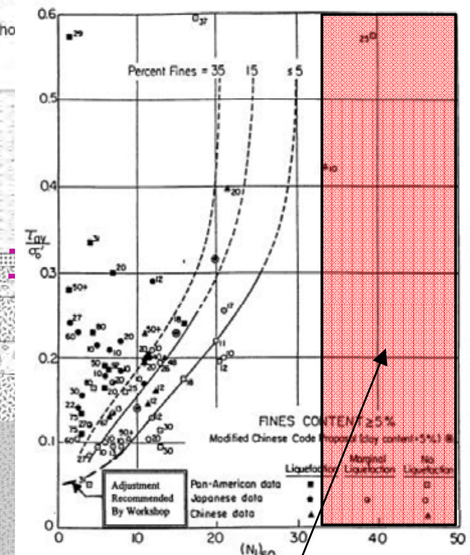
Drill Data







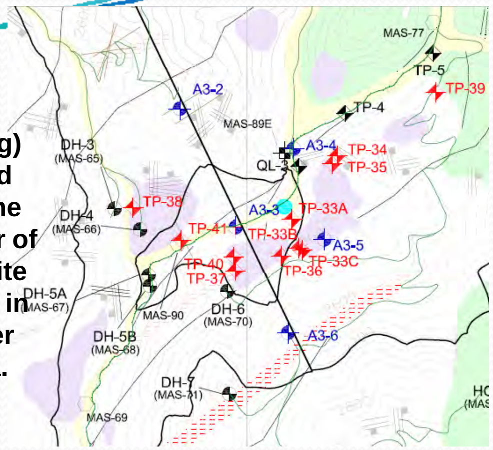


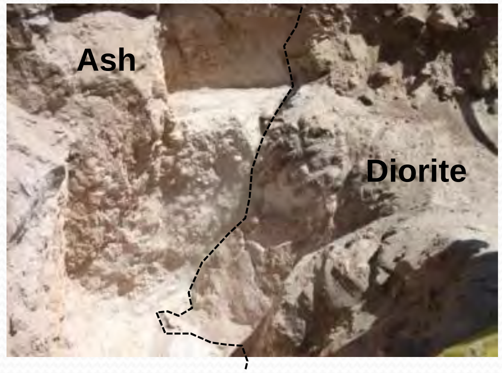
- **Drill/SPT data results of suggest material at base is very/extremely dense (hard) and is not likely to collapse.**
- **SPT data indicates a relative strength of φ = 35° to 40°.**
- **Liquefaction potential of basal ash layer is considered to be extremely low (i.e. non-liquefiable).**

Range of SPT-$N_{1(60)}$ values in ash >>30.

Test Pits & Material Characterization

Test pits (hand dug) excavated around the perimeter of the rhyolite tuff pods in the starter dam area.





In-situ - Sand Cone Densities of Unwelded Ash in Test Pits

Test Pit ID	Wet Density (g/cm^3)	Moisture Content (%)	Dry Density (g/cm^3)
TP-33b	1.49	0.50%	1.48
TP-34	1.46	0.40%	1.45
TP-35	1.40	1.30%	1.38
TP-40	1.47	1.30%	1.45
TP-41	1.38	0.60%	1.37
Average w/o TP-36	**1.44**	**0.82%**	**1.43**

Lab - Relative Density Tests (Sand Cone Material)

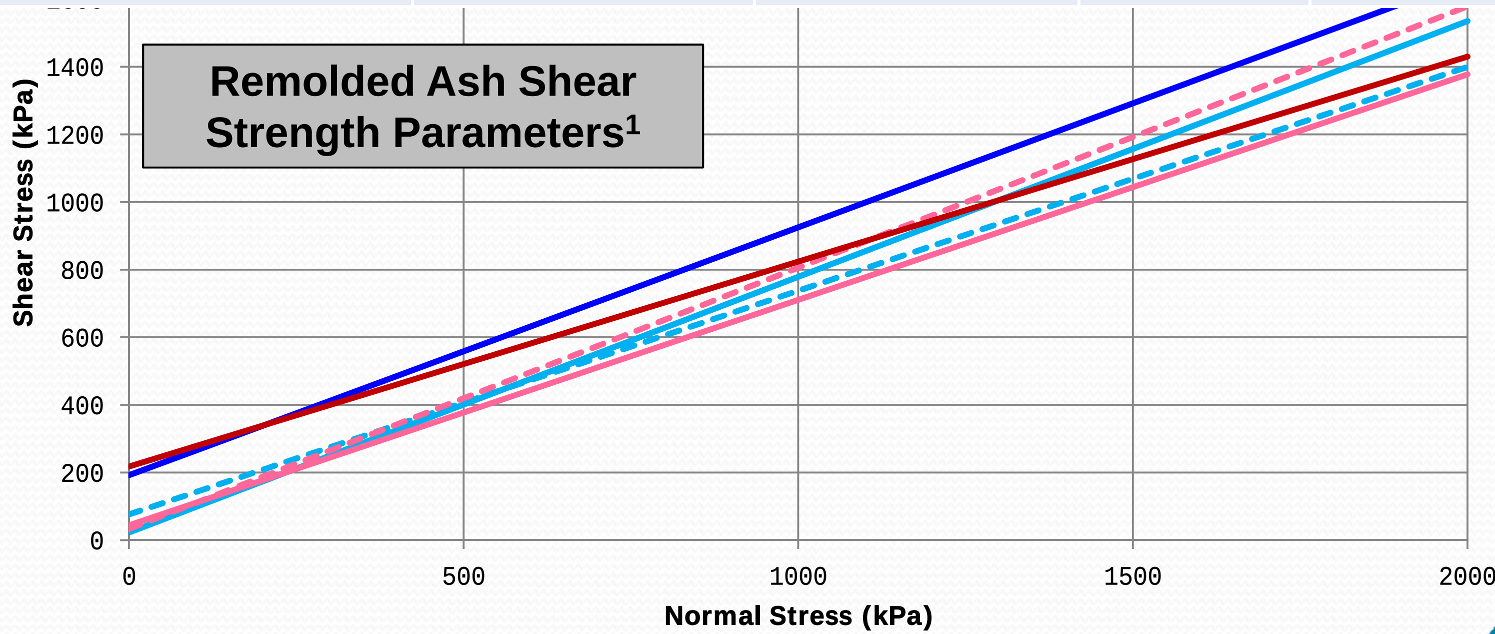
Trial	Min Densities		Max Densities	
	(pcf)	(g/cm^3)	(pcf)	(g/cm^3)
1	67.76	1.085	91.02	1.458
2	68.23	1.093	90.81	1.455
3	67.83	1.086		
Average	**67.94**	**1.09**	**90.92**	**1.46**

Targeted "Remolded" Densities for Shear Strength Tests

Target Density (g/cm^3)	Relative Density	Description
1.40	≈95%	Field Sand Cone Density, Very Dense
1.30	≈90%	Medium Dense

Test Pits & Material Characterization

Density (g/cm³)	Test	Condition	c' (kPa)	Φ'
1.30 (90%)	Direct Shear	Dry	33	38°
1.30 (90%)	Direct Shear	Saturated	44	34°
1.29 (88%)	CU Triaxial	Saturated	218	31°
1.39 (95%)	Direct Shear	Dry	76	34°
1.39 (95%)	Direct Shear	Saturated	23	37°
1.37 (94%)	CU Triaxial	Saturated	192	36°



1) potentially "destroys" the pre-existing granular structure in remolded soil testing – currently we are testing ash collected from MC liner samples at UC Berkeley)

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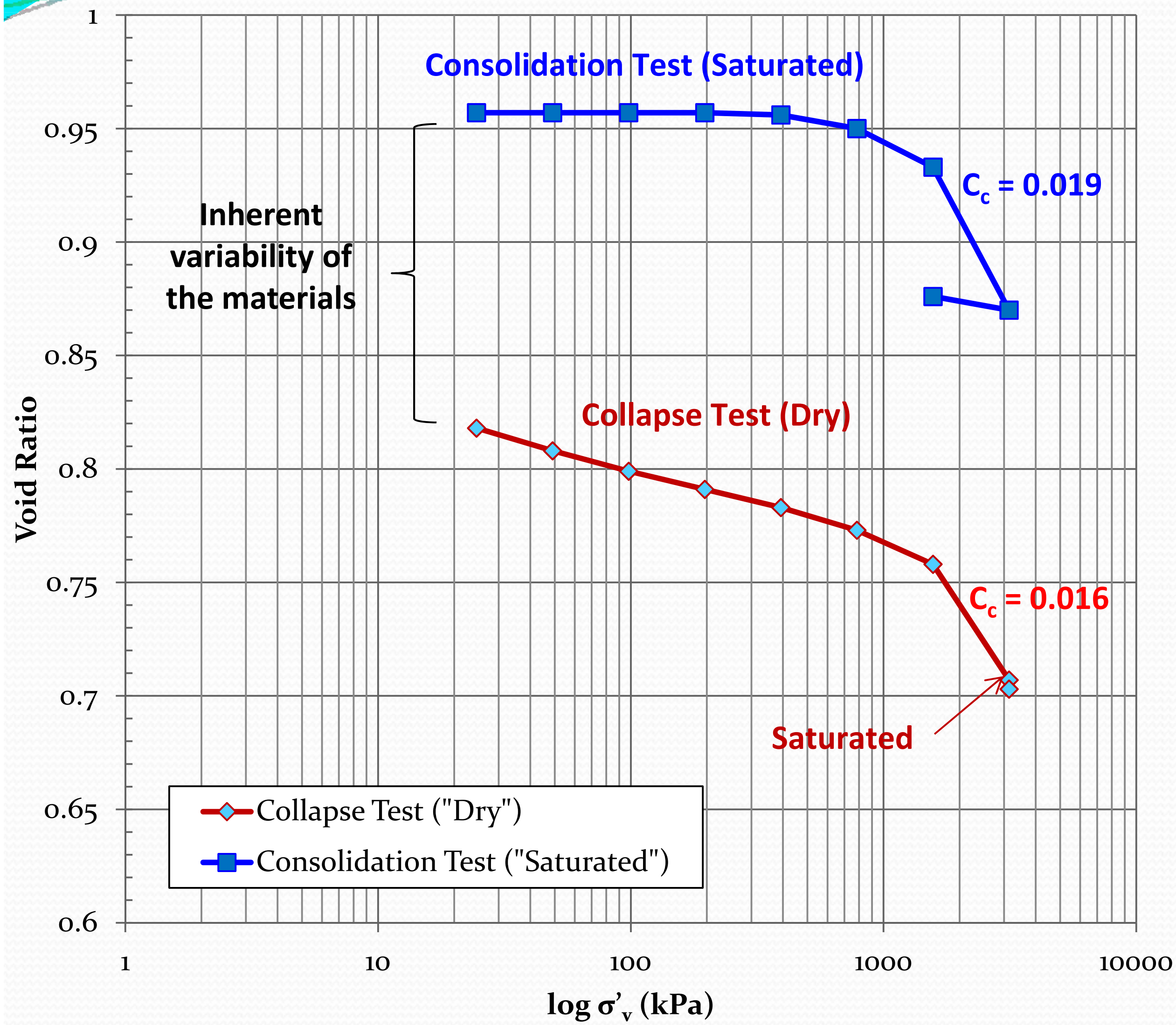
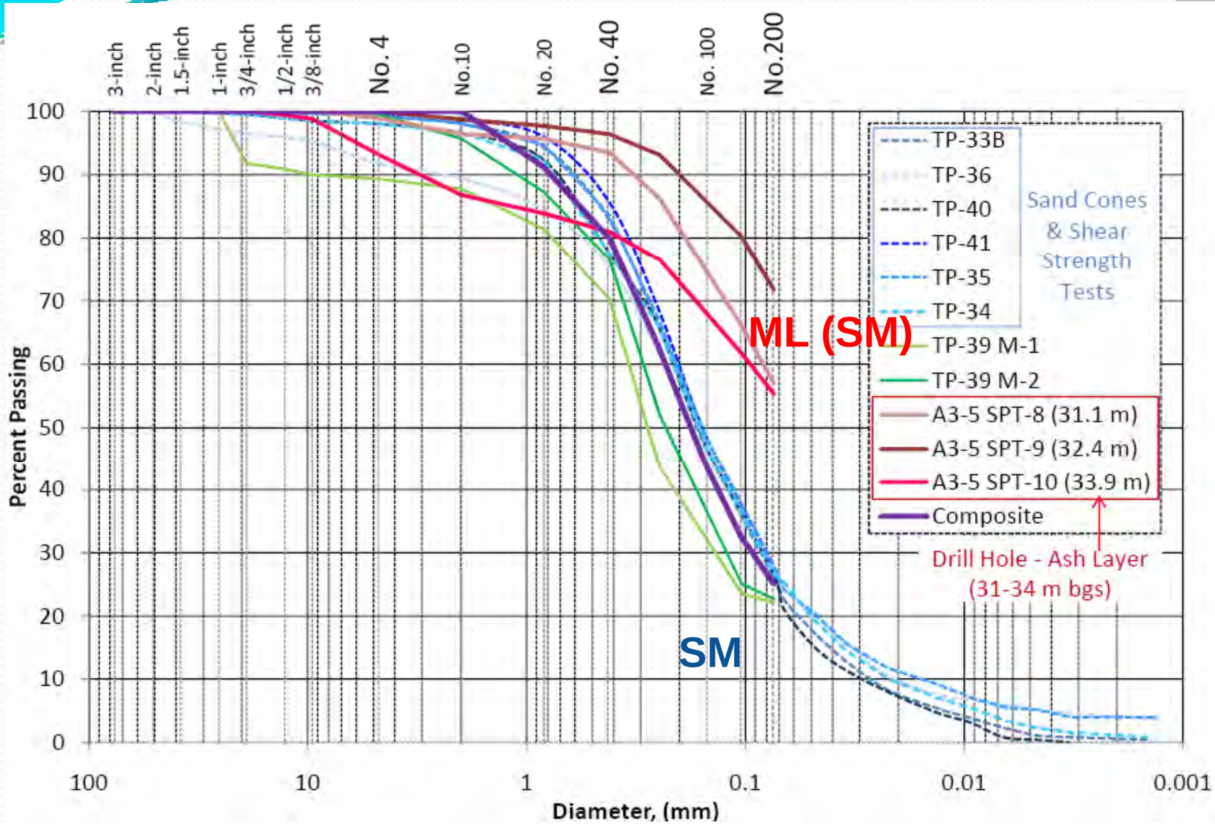
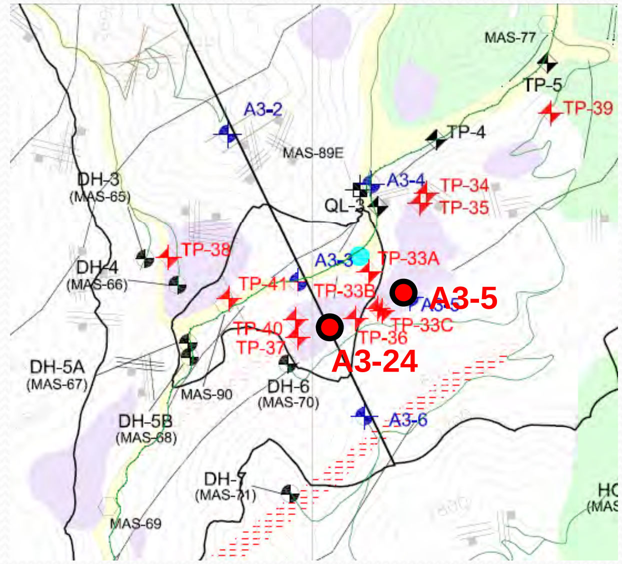
Test Pits & Material Characterization



Currently we are performing consolidation/collapse testing on additional tuff samples

Test Pits & Material Characterization





SM material collected from test pits excavated around the perimeter of the pods

ML (SM) material collected from drill hole A3-5 and A3-24 (additional results pending) samples collected from ash under the middle portion of the tuff "pod"

- **Consolidation/collapse and grain crushing has already occurred.**
- **Washing out of fines from the perimeter.**
- **Weathering and mineral degradation is greater internally under the pod.**

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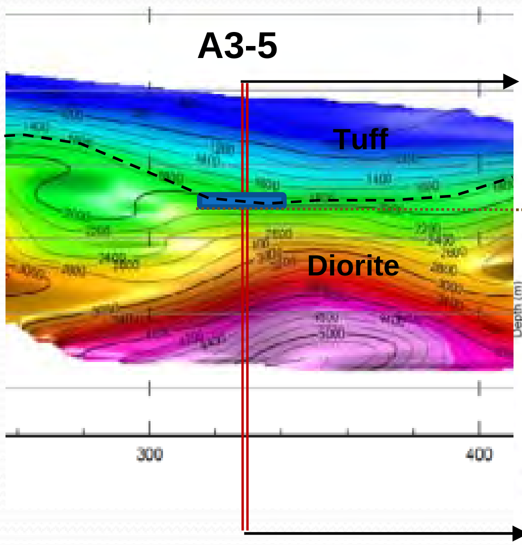
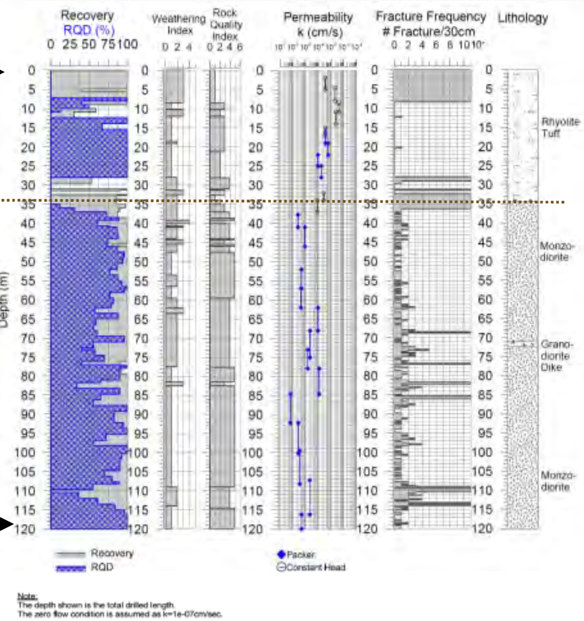
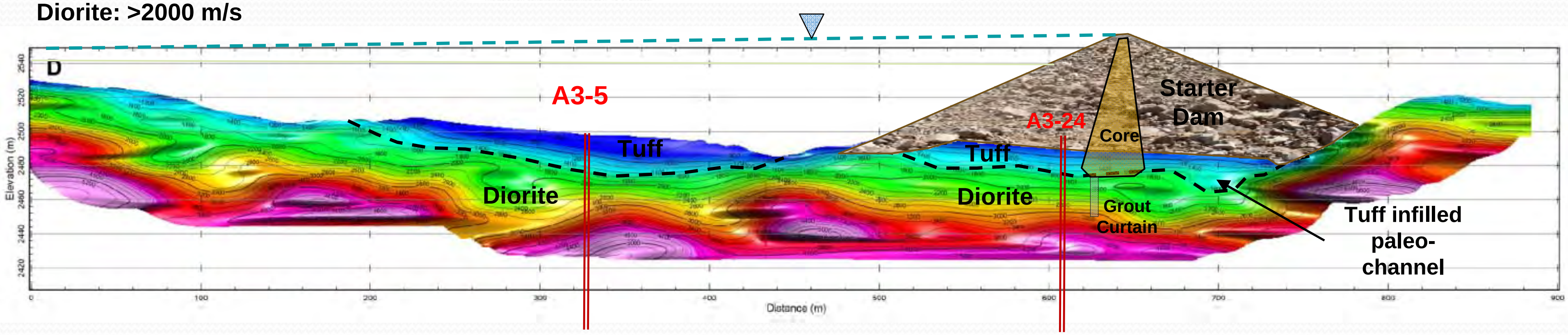
Geophysics (Refraction & MASW)





Compression Wave Velocity:
Base of Tuff: ~1600 to 1800 m/s
Diorite: >2000 m/s



View is looking uphill, to the SE

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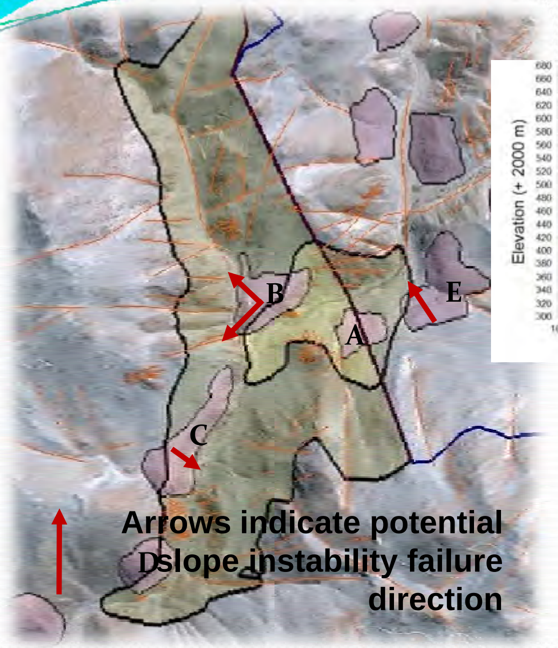
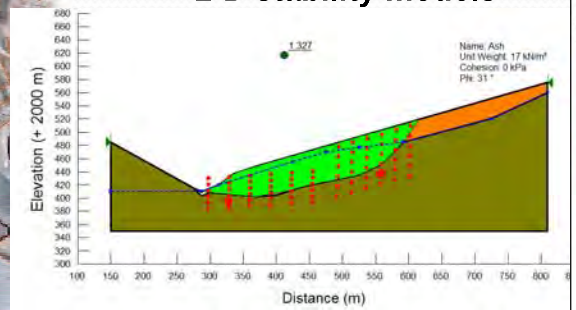
Stability & Seepage Modeling

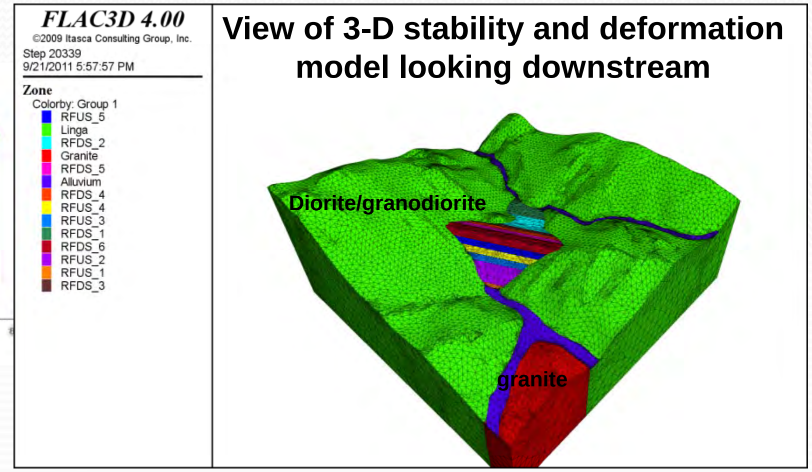


Arrows indicate potential slope instability failure direction

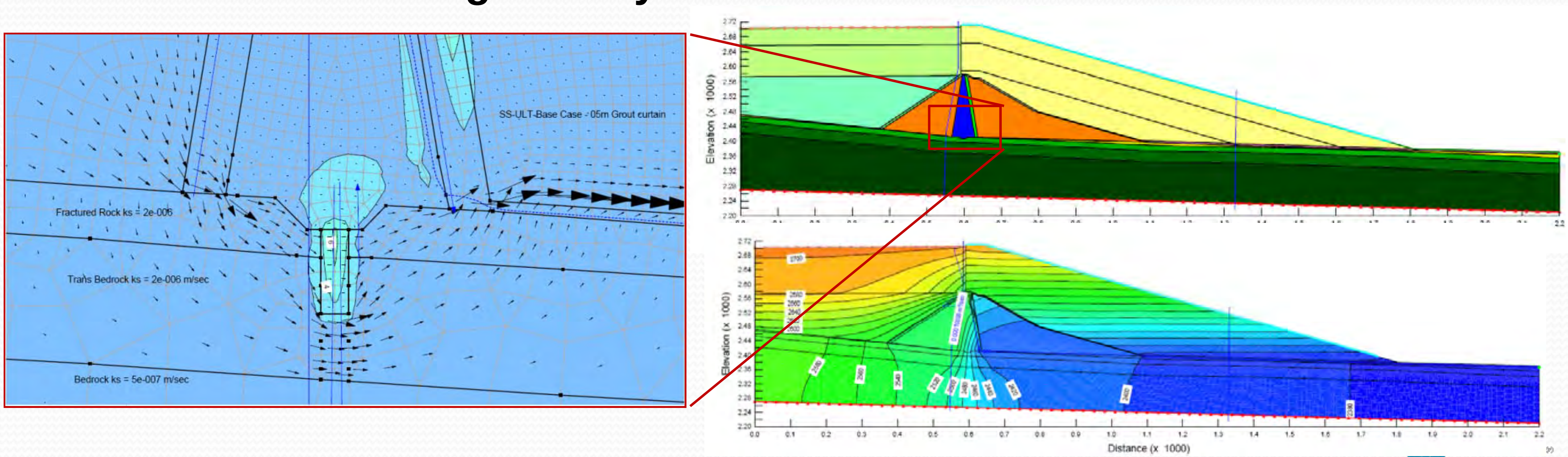
2-D stability models



View of 3-D stability and deformation model looking downstream



We are currently in the process of performing additional stability and seepage analysis for the overall structure and optimization of the design geometry.



Final Design
Preliminary Findings – Tuff "Pods"

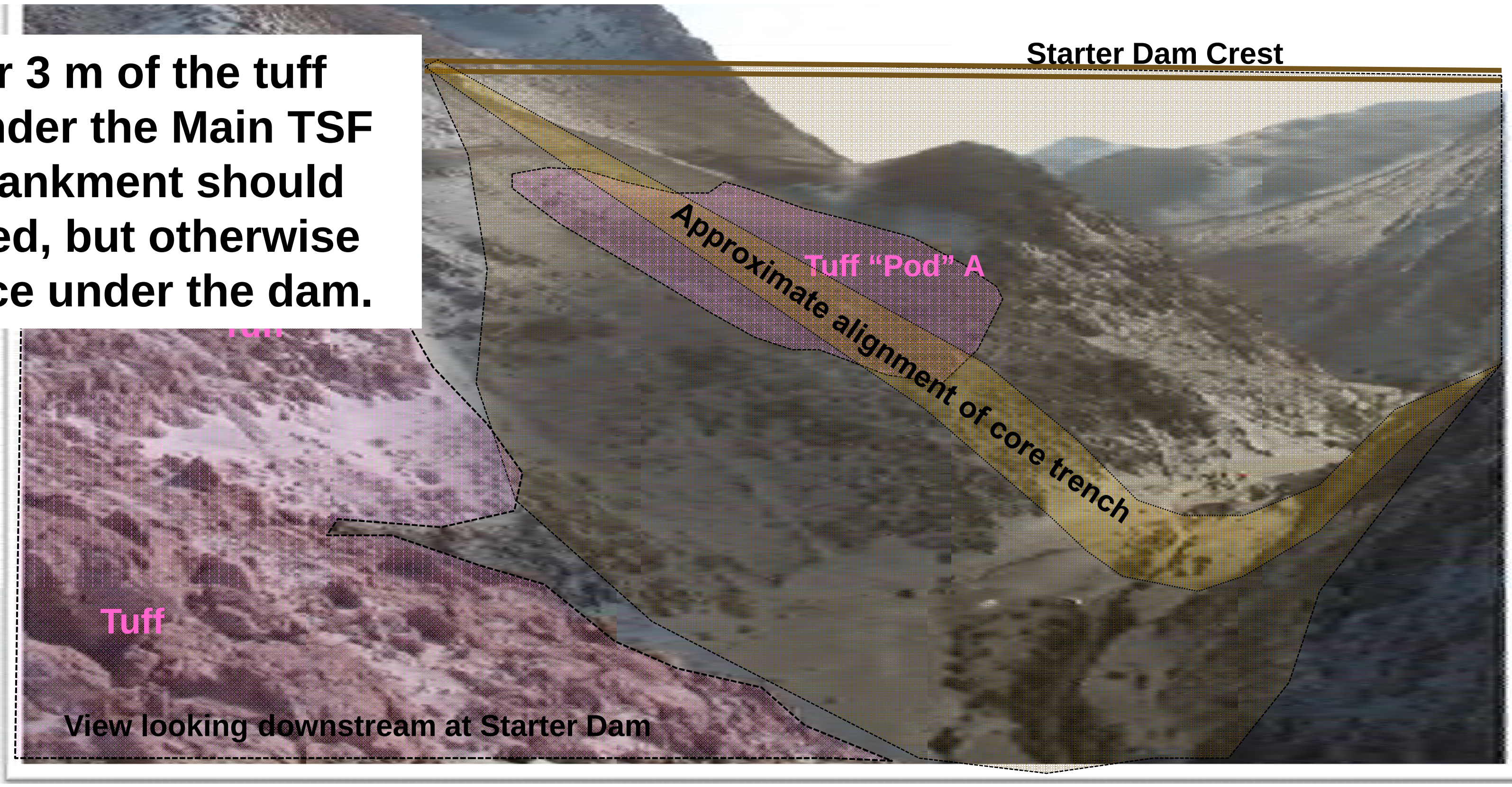
- Poorly-welded rhyolite tuff "pods" are 20 to 50 m thick and underlain by a 20 cm to 2 m thick layer of unconsolidated (un-welded) ash classified as a silty fine sand (SM) to sandy silt (ML).
- The poorly welded tuff has very high hydraulic conductivity along open and continuous fractures.
- The ash has a lower hydraulic conductivity than the overlying tuff and the underlying fractured diorite (a potential barrier to seepage along the base).
- "Pods" are discontinuous. (But irregular/undesirable seepage gradients could be realized if left in place around the core).
- Ash is very dense.
- There is a low potential for liquefaction of the underlying ash layer.
- Tuff and ash are consolidated with a low potential for additional consolidation/collapse or differential settlement.

Final Design
Preliminary Findings – Tuff “Pods”

1 - Tuff and ash <u>must</u> be completely excavated from below the core and filters/transitions.

2 – Additional seepage/stability modeling could show that there is little risk with leaving the tuff “pod” A under the main embankment alignment. However, at this time we are recommending removal of this “pod”.

3 - The upper 3 m of the tuff “pods” under the Main TSF sand embankment should be removed, but otherwise left in place under the dam.



Questions & Discussion