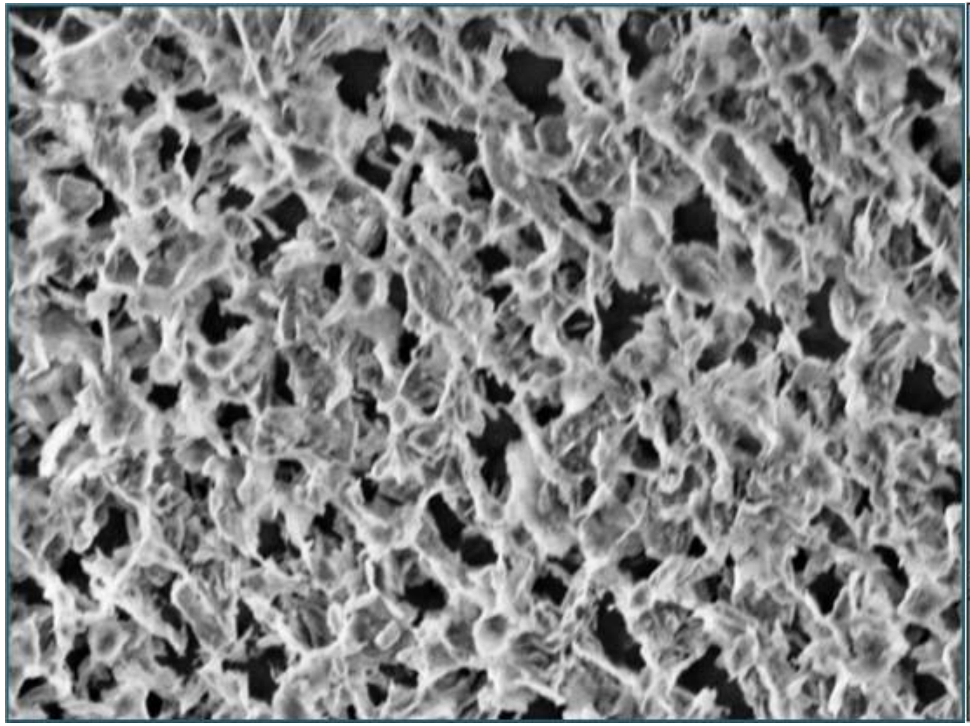
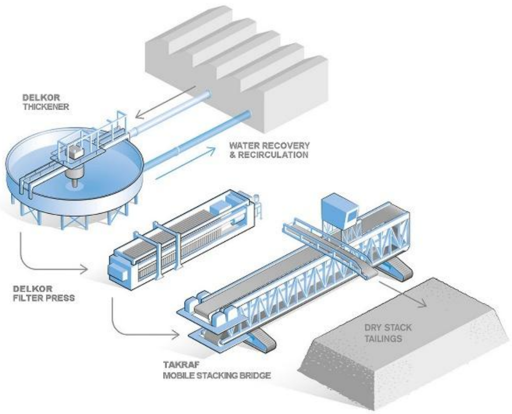
# *Classification of tailings by clay minerals and pore water chemistry as a basis for safe tailings disposal*

*A.J. Vietti and N.C. Steenkamp*



# Tailings Properties Overview

**Metallurgical Engineers**
Design process flow sheets –
Dewatering type and size




**Geotechnical Engineers**
Design containment structures –
TSF type and size

Design parameters are based on tailings property data derived from practical tests

No common method to classify tailings in order to understand their behavior – particularly for clay containing tailings

TAILINGS

# Tailings Properties Overview

VIETTI Slurrytec
Understanding slurry™

- Current framework for classifying tailings

| Tailings | Intrinsic Properties |
|---|---|
| Solids | • Particle size distribution<br>• Solids specific gravity<br>• Mineralogy<br>• Clay activity<br>• Water chemistry |
| Water | |

Poor understanding of how the <u>Intrinsic properties</u> of tailings relate to their <u>engineering properties</u>

| Engineering (Derived) Properties | Process Flow Sheet |
|---|---|
| **Dispersive properties**<br>• Cylinder test<br>• Pin-hole test<br>• Crumb test | Dewatering |
| **Sedimentation properties**<br>• Setting test<br>• Thickener test | |
| **Consolidation properties**<br>• Triaxial test<br>• Proctor test | Transport |
| **Permeability properties**<br>• Filter test<br>• Falling/static head test | |
| **Rheological properties**<br>• Bob and Cup test<br>• Vane test<br>• Atterberg tests | Deposition |

# Current Tailings Classification Method

- Geotechnical Engineers commonly use the Unified Soil Classification System (USCS) for soils.
- Classify by particle size (<u>intrinsic property)</u> and by Atterberg limits (<u>water quality dependent</u>) into cohesive and non-cohesive groups

**UNIFIED SOIL CLASSIFICATION AND SYMBOL CHART**

| | | |
|---|---|---|
| **COARSE-GRAINED SOILS** (more than 50% of material is larger than No. 200 sieve size.) | | |
| **GRAVELS** More than 50% of coarse fraction larger than No. 4 sieve size | Clean Gravels (Less than 5% fines) | |
| | GW | Well-graded gravels, gravel-sand mixtures, little or no fines |
| | GP | Poorly-graded gravels, gravel-sand mixtures, little or no fines |
| | Gravels with fines (More than 12% fines) | |
| | GM | Silty gravels, gravel-sand-silt mixtures |
| | GC | Clayey gravels, gravel-sand-clay mixtures |
| **SANDS** 50% or more of coarse fraction smaller than No. 4 sieve size | Clean Sands (Less than 5% fines) | |
| | SW | Well-graded sands, gravelly sands, little or no fines |
| | SP | Poorly graded sands, gravelly sands, little or no fines |
| | Sands with fines (More than 12% fines) | |
| | SM | Silty sands, sand-silt mixtures |
| | SC | Clayey sands, sand-clay mixtures |
| **FINE-GRAINED SOILS** (50% or more of material is smaller than No. 200 sieve size.) | | |
| **SILTS AND CLAYS** Liquid limit less than 50% | ML | Inorganic silts and very fine sands, rock flour, silty of clayey fine sands or clayey silts with slight plasticity |
| | CL | Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays |
| | OL | Organic silts and organic silty clays of low plasticity |
| **SILTS AND CLAYS** Liquid limit 50% or greater | MH | Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts |
| | CH | Inorganic clays of high plasticity, fat clays |
| | OH | Organic clays of medium to high plasticity, organic silts |
| **HIGHLY ORGANIC SOILS** | PT | Peat and other highly organic soils |

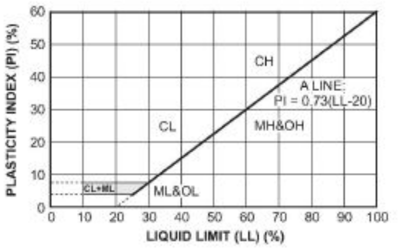
**LABORATORY CLASSIFICATION CRITERIA**

| | | |
|---|---|---|
| GW | $C_u = \frac{D_{60}}{D_{10}}$ greater than 4; $C_c = \frac{D_{30}}{D_{10} \times D_{60}}$ between 1 and 3 | |
| GP | Not meeting all gradation requirements for GW | |
| GM | Atterberg limits below "A" line or P.I. less than 4 | Above "A" line with P.I. between 4 and 7 are borderline cases requiring use of dual symbols |
| GC | Atterberg limits above "A" line with P.I. greater than 7 | |
| SW | $C_u = \frac{D_{60}}{D_{10}}$ greater than 4; $C_c = \frac{D_{30}}{D_{10} \times D_{60}}$ between 1 and 3 | |
| SP | Not meeting all gradation requirements for GW | |
| SM | Atterberg limits below "A" line or P.I. less than 4 | Limits plotting in shaded zone with P.I. between 4 and 7 are borderline cases requiring use of dual symbols. |
| SC | Atterberg limits above "A" line with P.I. greater than 7 | |

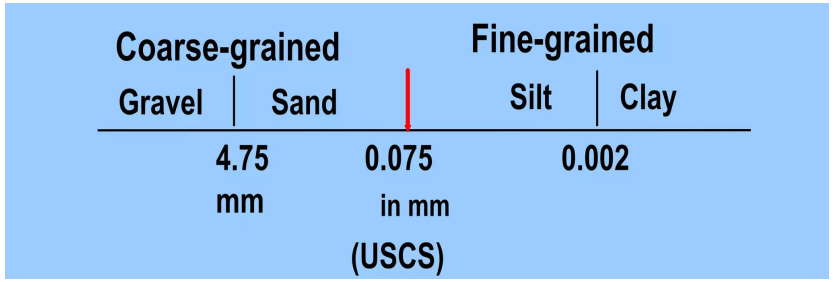
Determine percentages of sand and gravel from grain-size curve. Depending on percentage of fines (fraction smaller than No. 200 sieve size), coarse-grained soils are classified as follows:

Less than 5 percent ........ GW, GP, SW, SP
More than 12 percent ........ GM, GC, SM, SC
5 to 12 percent ........ Borderline cases requiring dual symbols

**PLASTICITY CHART**




California Dept of Transport – Unified Soil Classification System.

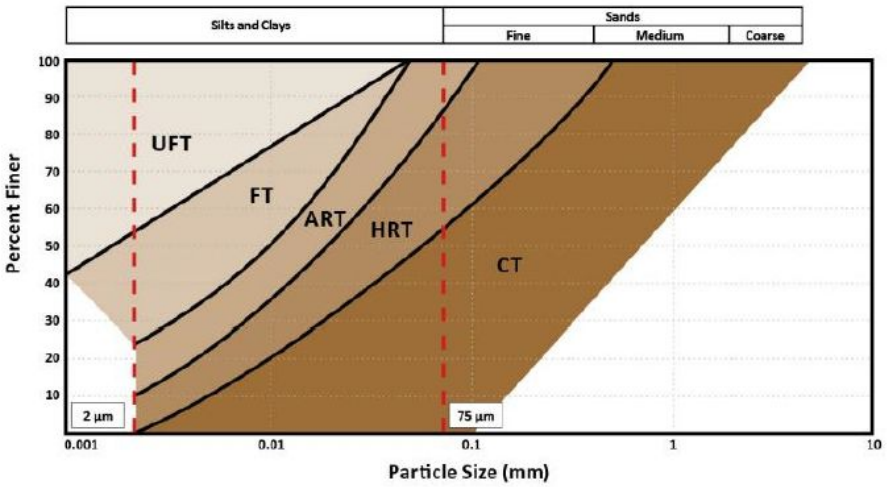


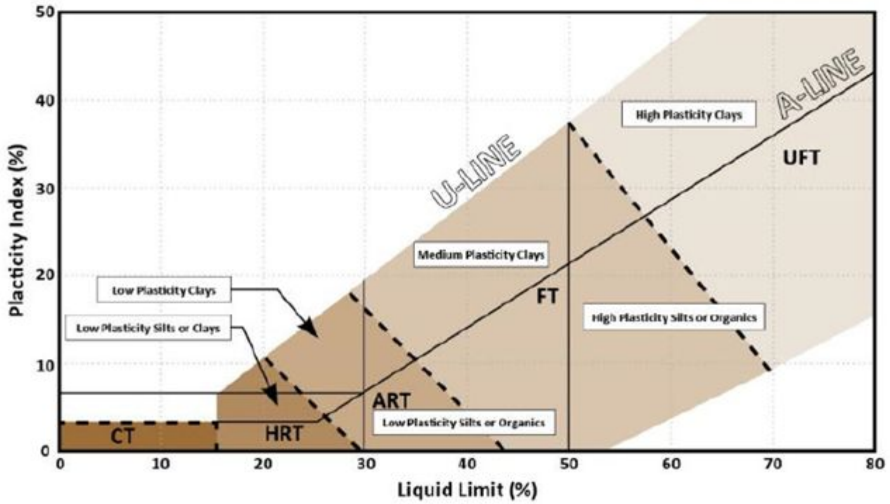

| Soil Type | Prefix | Sub Group | Suffix |
|---|---|---|---|
| Gravel | G | Well graded | W |
| Sand | S | Poorly graded | P |
| Silt | M | Silty | M |
| Clay | C | Clayey | C |
| Organic | O | LL<50 | L |
| Peat | Pt | LL>50 | H |

# Current Tailings Classification Method

- Recently (2021) ICOLD introduced a “Tailings Dam Design Technology Update” suggesting tailings be classified into 5 groups.
- Provide “property templates” to classify tailings

| Tailings Type | Symbol | Description (compare) | Example of mineral/ore |
|---|---|---|---|
| Coarse tailings | CT | Silty SAND, non-plastic | Salt, mineral sands, coarse coal rejects, iron ore sands |
| Hard Rock tailings | HRT | Sandy SILT, non to low plasticity | Copper, massive sulphide, nickel, gold |
| Altered Rock tailings | ART | Sandy SILT, trace of clay, low plasticity, bentonitic clay content | Porphyry copper with hydrothermal alteration, oxidized rock, bauxite. leaching processes |
| Fine tailings | FT | SILT, with trace to some clay, low to moderate plasticity | Iron ore fines, bauxite (red mud), fine coal rejects, leaching processes, metamorphosed/weathered polymetallic ores |
| Ultra Fine tailings | UFT | Silty CLAY, high plasticity, very low density and hydraulic conductivity | Oil sands (fluid fine tailings), phosphate fines; some kimberlite and coal fines |




International Commission on Large Dams 2021, *Bulletin 181 Tailings Dam Design Technology Update*, Paris.

# Current Tailings Classification Method

- Important questions to consider when classifying clay containing (cohesive) tailings

| Tailings | Intrinsic (Index) Properties |
| --- | --- |
| Solids | • Particle size distribution<br>• Solids specific gravity<br>• Mineralogy<br>• Clay activity |
| Water | • Water quality |

*Solids Component*

"How much Fines in my tailings?"

"How much Active Clays in the Fines?"

*Water Component*

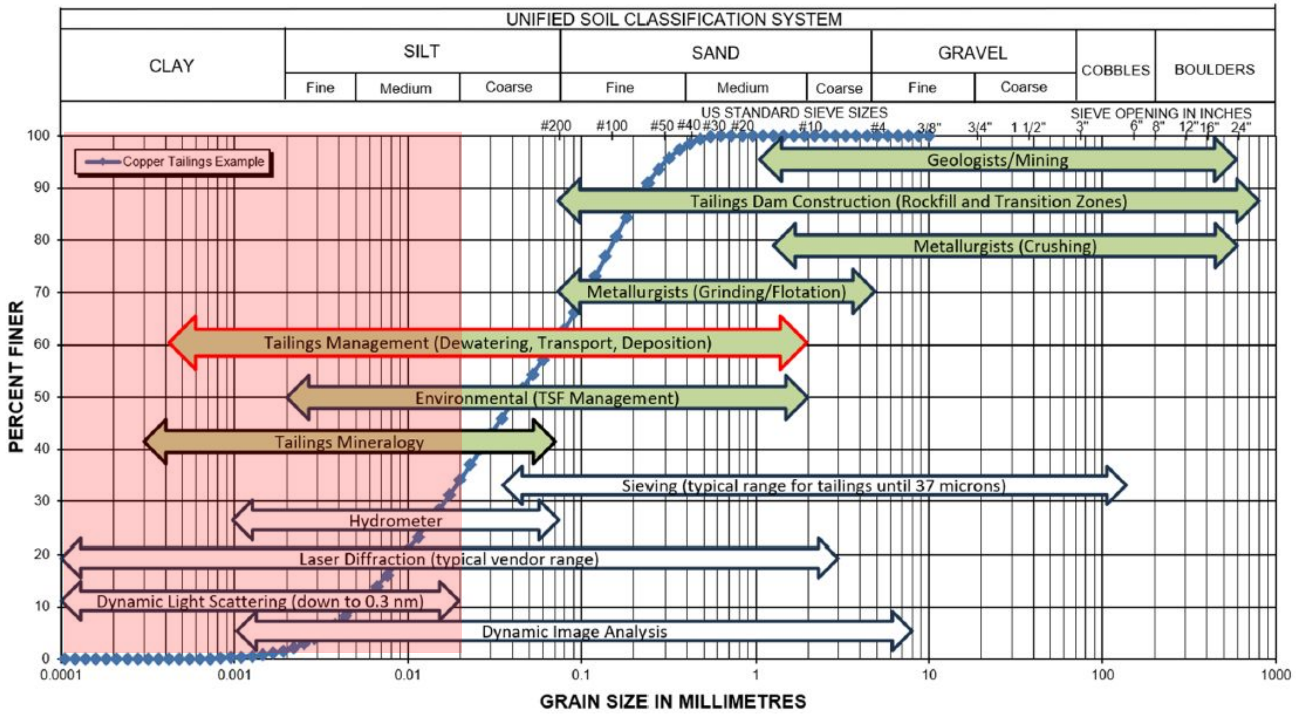
"If I have Active Clays, is my water dispersive?"

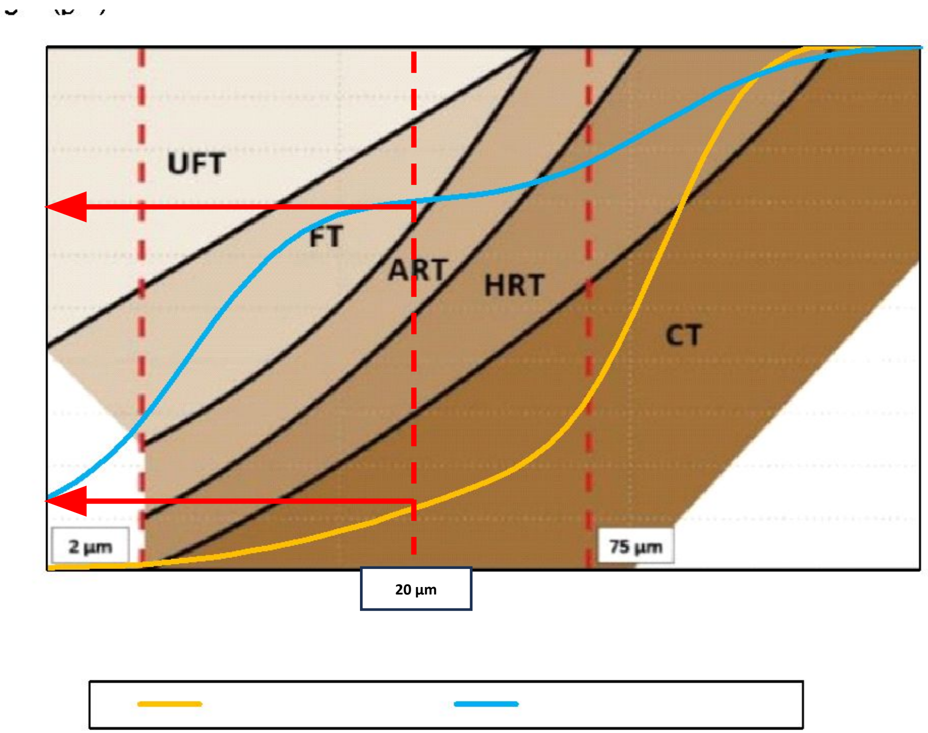
# Classifying Tailings: Solids Component

- How much Fines do I have in my tailings?

## Solids Particle Size

- Define -20µm as “Fines” fraction (rather than -2µm as “Clay”)
- Accepted as a valid criteria for classifying tailings behavior for dewatering and backfill applications




Engels, J, Guzman, J & Valdes, S 2025, 'Tailings particle size distribution methodology: the good, the bad, and the ugly', in AB Fourie, A Copeland, V Daigle & C MacRobert (eds), *Paste 2025: Proceedings of the 27th International Conference on Paste, Thickened and Filtered Tailings*, Australian Centre for Geomechanics, Perth, pp. 165-180,

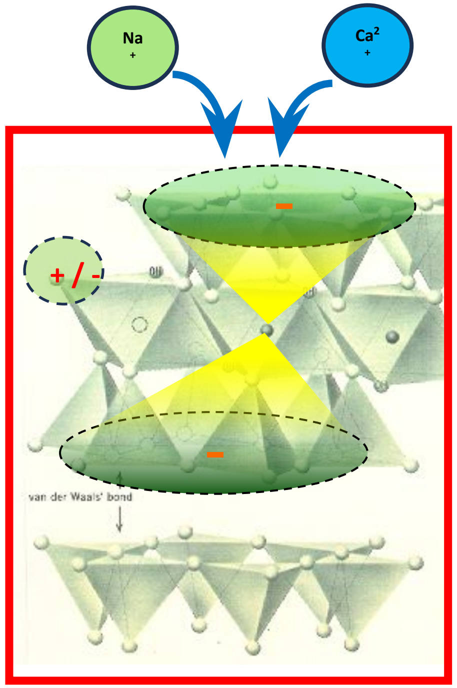
# Classifying Tailings: Solids Component



- How much Active Clays do I have in my Fines?

**Active Clays have charged surfaces**

- *EDGES – negative or positive charge depending on pH when in water.*
- *SURFACE – negative which can exchange cations when in water.*




Grimm, RE, 1968, ‘Clay mineralogy (2nd ed)’, McGraw Hill, New York.

| Type | Charge on layer | Dioctahedral | Trioctahedral |
|---|---|---|---|
| 1:1 | (x ~ 0) | **Kaolinite** kaolinite, dickite, nacrite, halloysite | **Serpentine** amesite, chrysotile, antigorite, lizardite |
| 2:1 | (x ~ 0) | **Pyrophyllite** | **Talc** |
| | (x ~ 0.2 – 0.6) | **Smectite** montmorillonite, beidellite, nontronite | **Smectite** saponite, hectorite, stevensite |
| | (x ~ 0.6 – 0.9) | **Vermiculite** | **Vermiculite** |
| | (x ~ 0.75 – 0.9) | **Illite** Glauconite | |
| | (x ~ 1.0) | **Micas** muscovite, paragonite, phengite, celadonite | **Micas** phlogopite, biotite, lepidolite |
| | (x ~ 2.0) | **Brittle micas** margarite, clintonite | |
| | (x ~ variable) | **Chlorites** donbassite | **Chlorites** clinochlore, chamosite, ripidolite |
| | **(x ~ variable)** | | Sepiolites, Palygorskites |

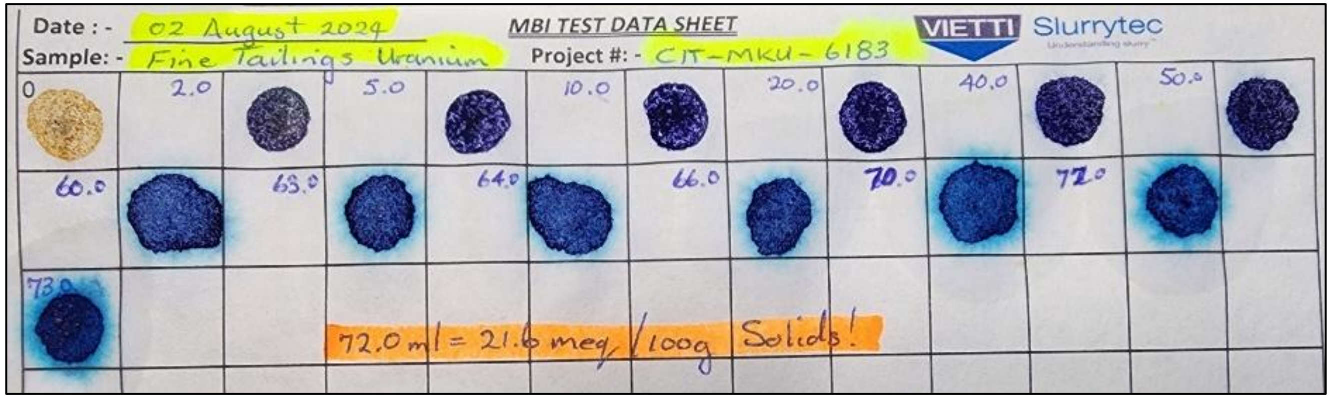
*Active/Swelling Clays*

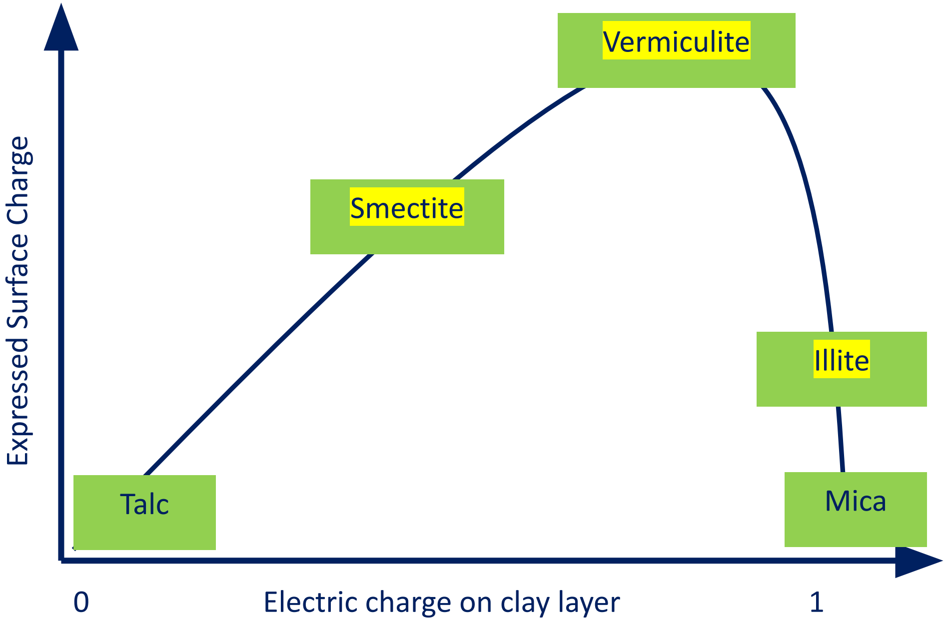
# Classifying Tailings: Solids Component

- How much Active Clays do I have in my Fines?

**Clay Activity (expressed surface charge)**

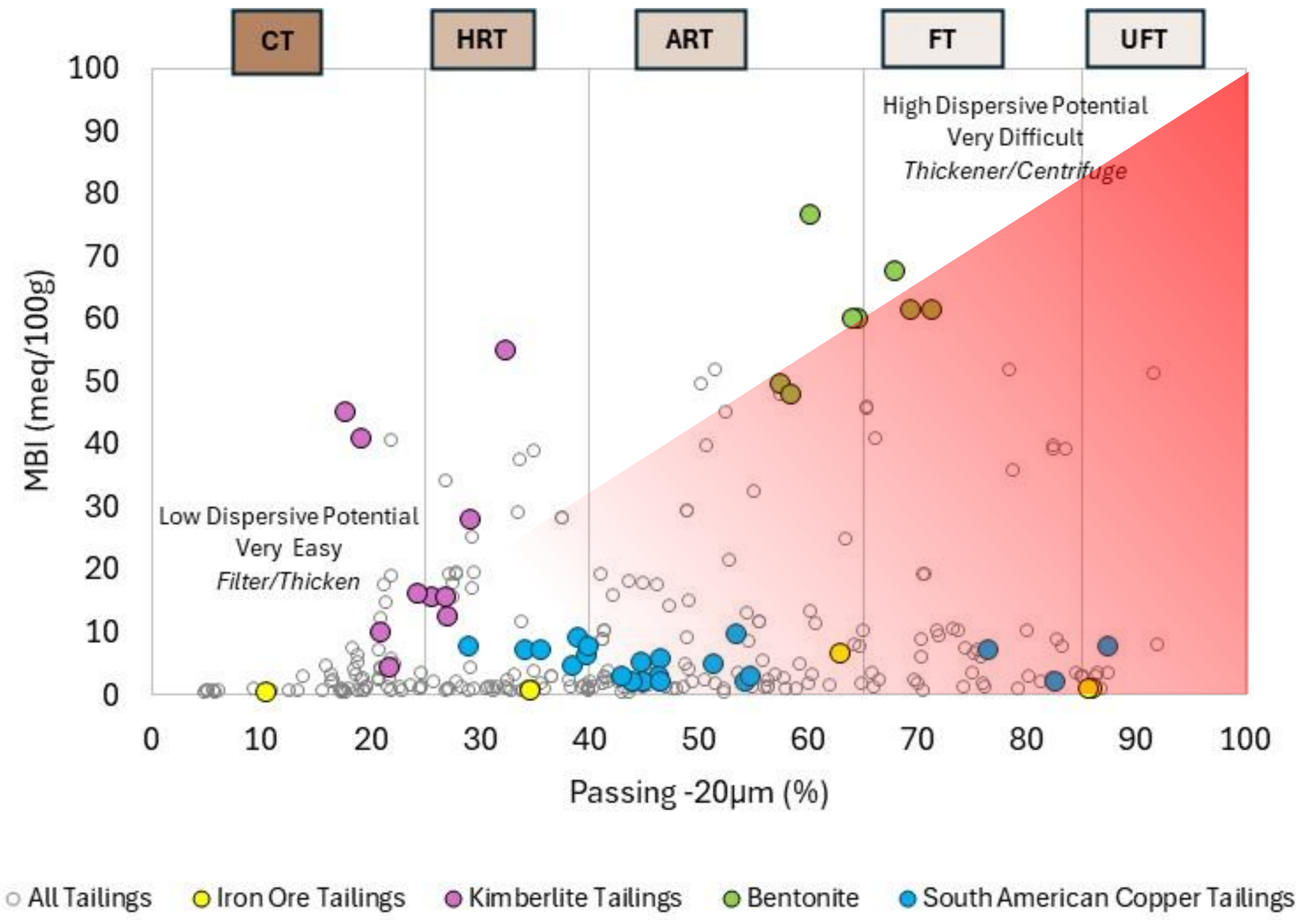
- Methylene Blue Index Method - Dye titration method to determine clay surface charge/area
- Standard Test Method for Methylene Blue Index of Clay (ASTM Standard C837)
- Define <15 meq/100g threshold as lower limit of Active/Swelling clay



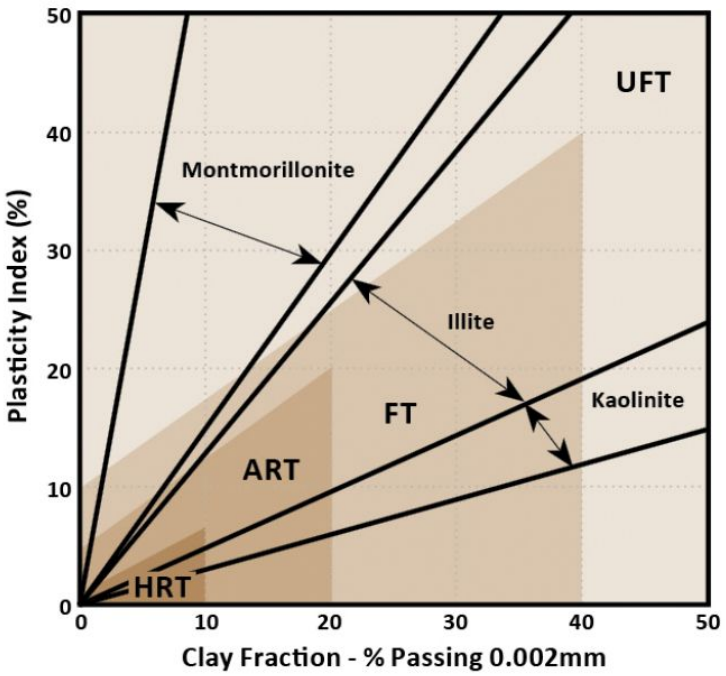




Kaminsky, H 2014, 'Demystifying the Methylene Blue Index', 4th Int Conf. Oil Sands Proceedings,

# Classifying Tailings: Solids Component



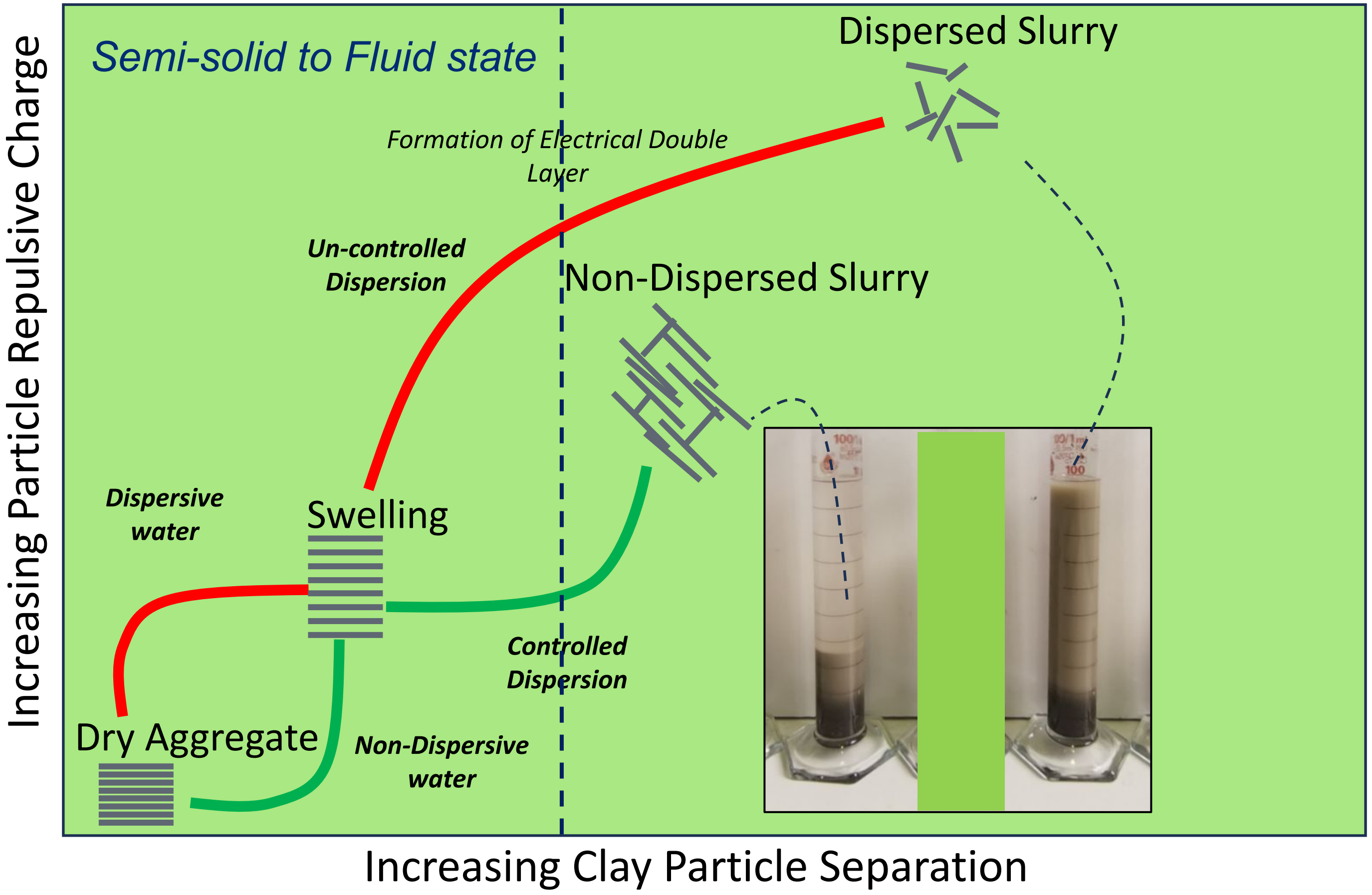

Similar to the Skempton Activity Chart




The Active Clay dispersive properties depend on the contacting water quality

# Classifying Tailings: Water Component

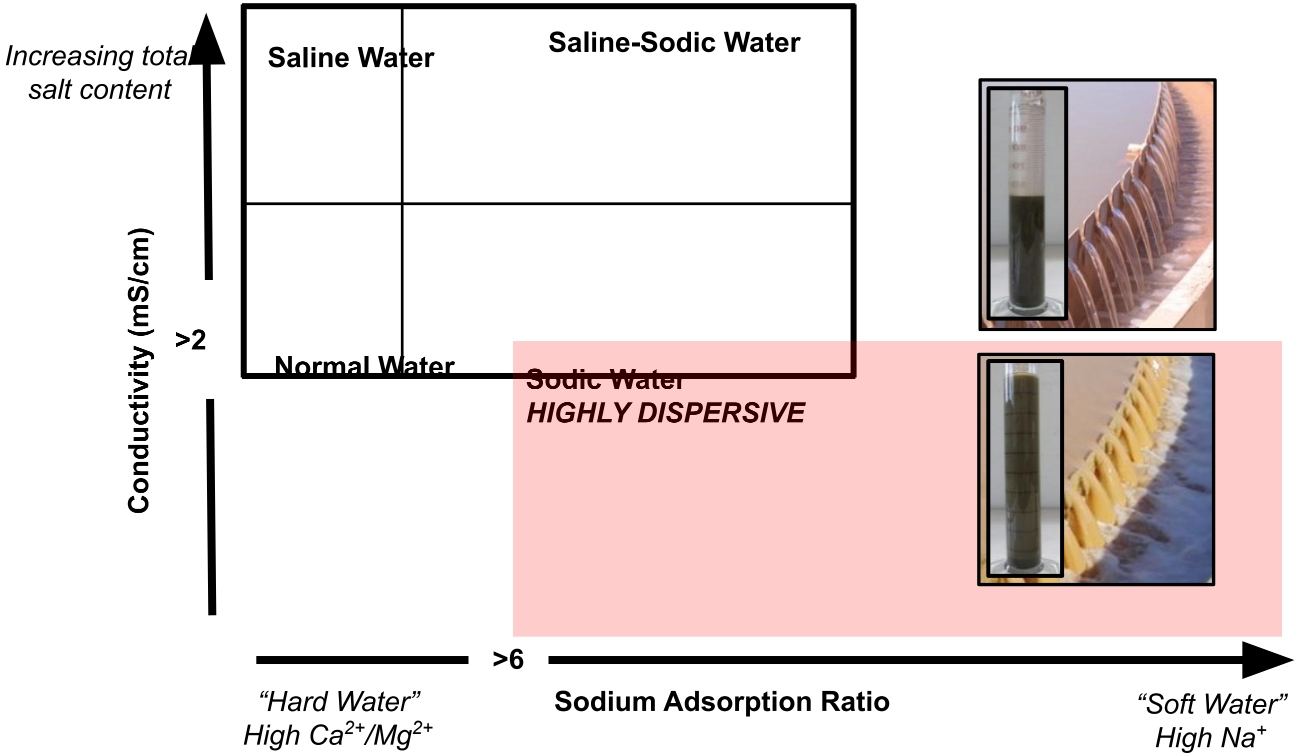
- If I have Active Clays, is my water dispersive?

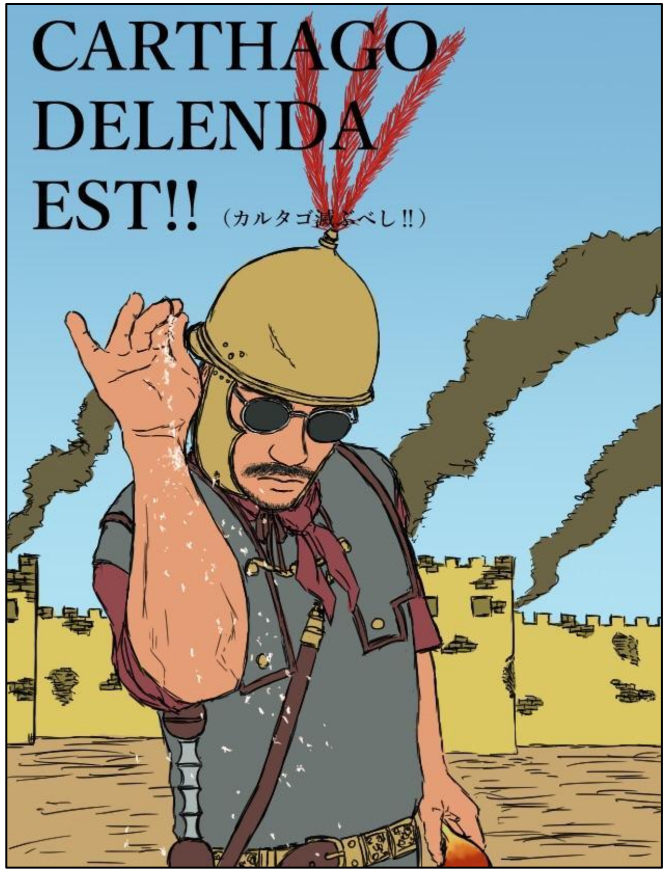



Rengasamy, P 2018, 'Irrigation water quality and soil structure stability – A perspective with some new insights'. Agronomy, 8, pp 72-85.

# Classifying Tailings: Water Component

- Tailings containing Active Clays have similar DISPERSIVE properties as Saline/Sodic soils



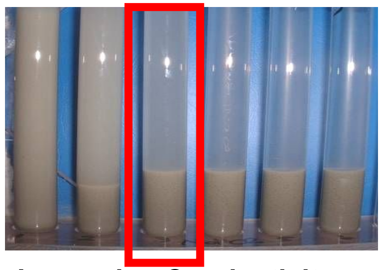




Fitzpatrick, RW, Boucher SC, Naidu R and Fritsch E 1994, 'Environmental consequences of soil sodicity' *Australian Journal of Soil Research,* vol 32, pp 1068-1093.

# Classifying Tailings: Water Component

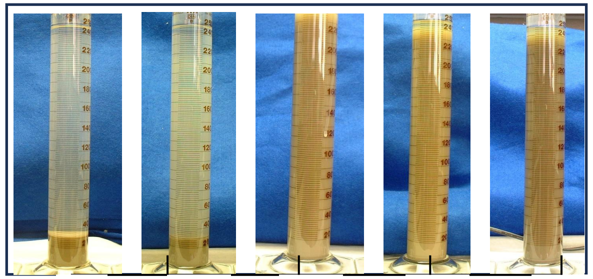
## 1. Conductivity of Water (mS/cm)
- Measured by conductivity meter
- Units defined in mS/cm
- Define <2.0 mS/cm as TEC for dispersion

Threshold Electrolyte Concentration(TEC)



*Increasing Conductivity*

## 2. Sodium Adsorption Ratio of Water
- Water Quality Analysis
- Define >6.0 as threshold for dispersion
- Equation (in meq/l): $$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}}$$

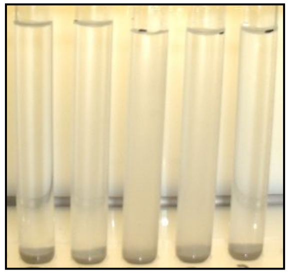


0 25 50 75 100

*Increasing SAR*

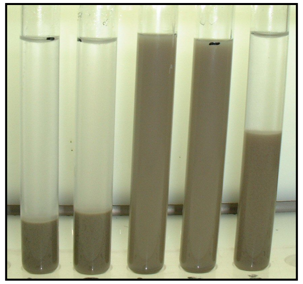
## 3. pH of Water
- Measured using a pH meter
- Define 8 to 10 for dispersion at >6 SAR

4 6 8 10 11.5



***SAR <6***

4 6 8 10 11.5



***SAR >6***

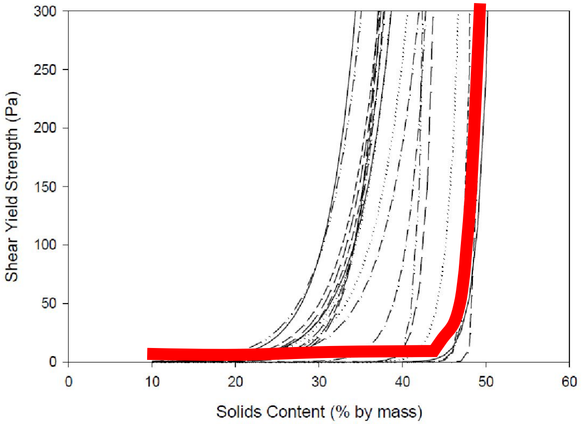
Vietti, AJ 2012, 'Know your chemistry – suspension and compaction behaviour of paste'. in RJ Jewell & AB Fourie (eds), *Proceedings of the 7th International Seminar on Paste and Thickened Tailings*, Australian Centre for Geomechanics, Cape Town.

# Classifying Tailings: Water Component



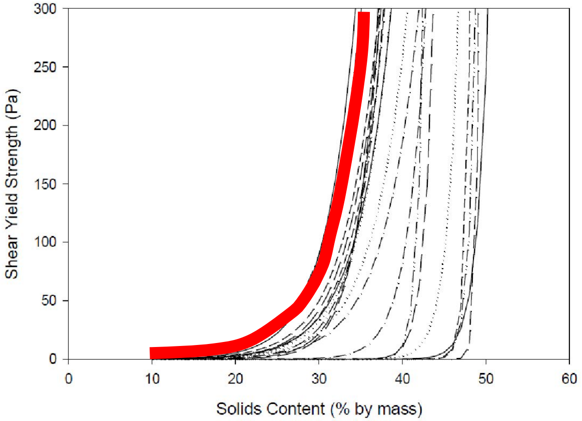
Dispersive slurry

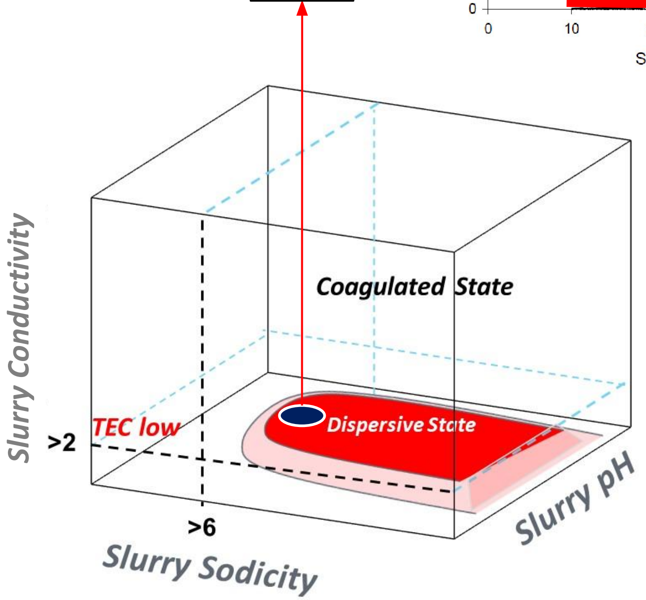
“Hockey stick shape” Rheological property

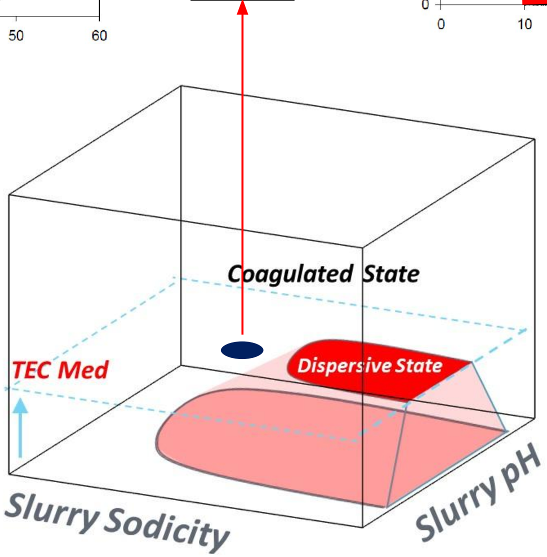


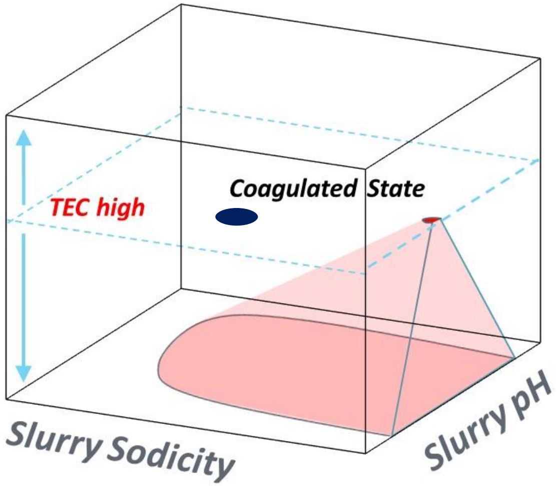

Non-dispersive slurry

“Banana shape” Rheological property




*In waters with low Salinity (<2 mS/cm) and Sodicity >6, tailings highly dispersive*

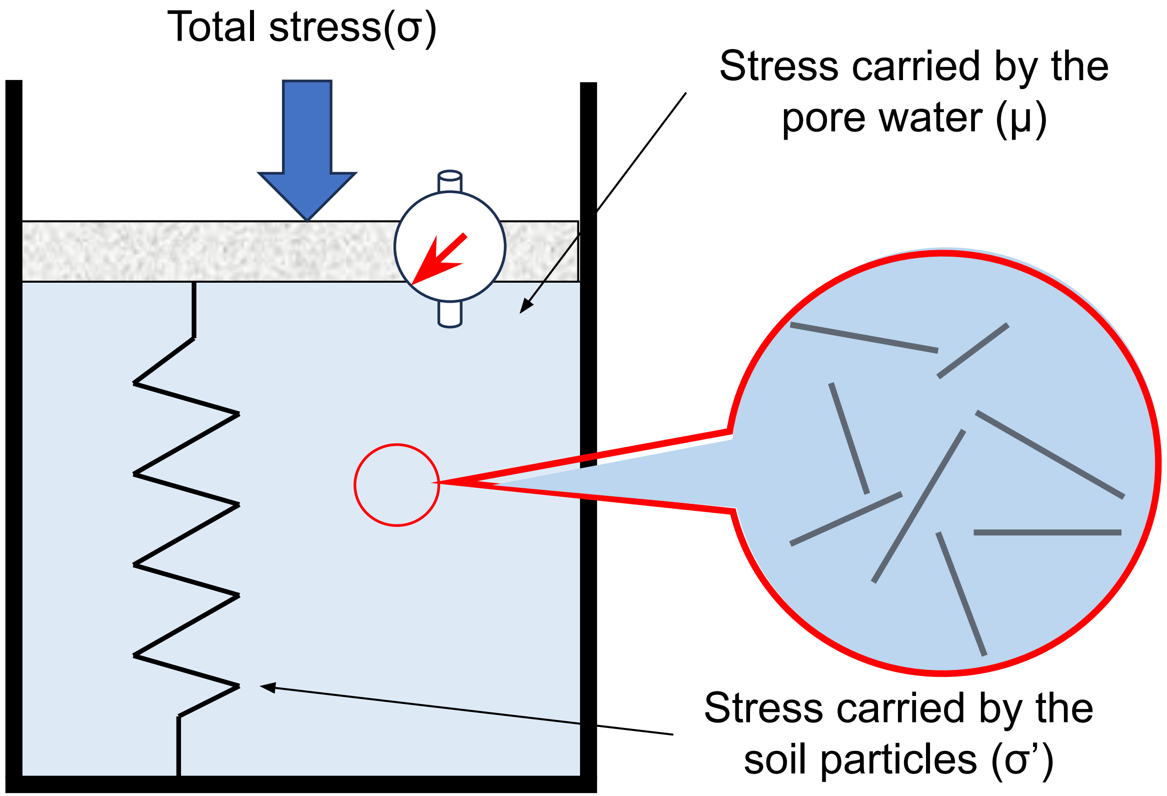
*As Salinity increases only tailings with very high Sodicity remain dispersive*

*At very high Salinity (sea water) all tailings settle*

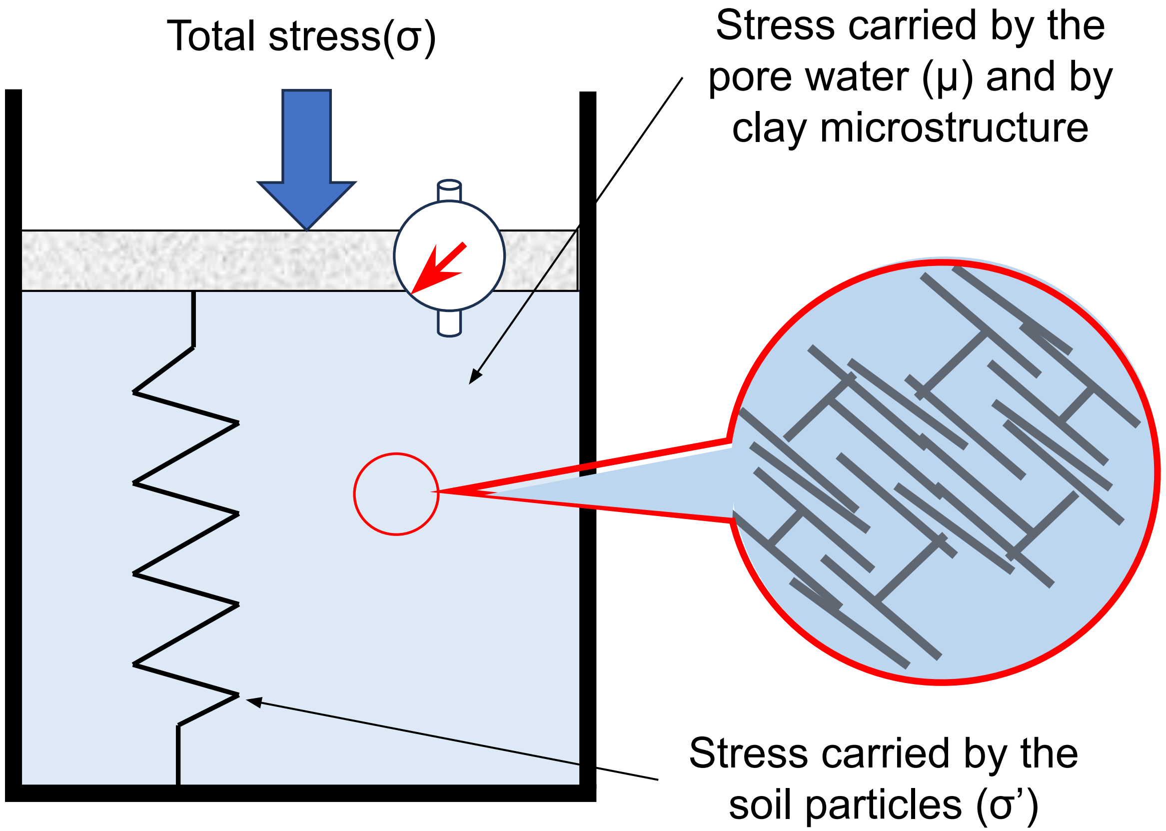
Bennett, JMcL and Raine SR 2012, ‘The soil specific nature of threshold electrolyte concentration analysis’ *Australian Society of Soil Science*.

# Tailings Properties Overview

*Dispersive Cohesive Tailings*



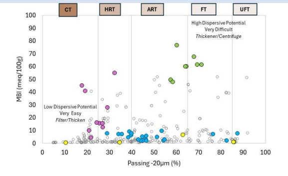

*Non-dispersive Cohesive Tailings*

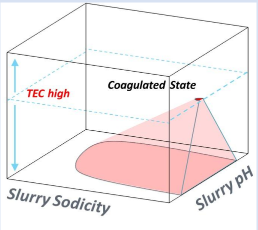


# Tailings Properties Overview

- Why classifying tailings can improve the “Observational Method” for TSF management

| Tailings | Intrinsic Properties |
|---|---|
| Solids | • Particle size distribution<br>• Solids specific gravity<br>• Mineralogy<br>• Clay activity<br>• Water chemistry |
| Water | |






| Engineering Properties | Process Flow Sheet Design | TSF Design and Operating Approach |
|---|---|---|
| **Dispersive properties**<br>• Cylinder test<br>• Pin-hole test<br>• Crumb test | Dewatering | ***PERFORMANCE-BASED DESIGN*** |
| **Sedimentation properties**<br>• Setting test<br>• Thickener test | | |
| **Consolidation properties**<br>• Triaxial test<br>• Proctor test | Transport | |
| **Permeability properties**<br>• Filter test<br>• Falling/static head test | | |
| **Rheological properties**<br>• Bob and Cup test<br>• Vane test<br>• Atterberg tests | Deposition | |

Proactive Data Driven Iterative Evaluation

# Conclusion

1. Propose a 2-tier approach for classifying tailings
   - Solids Component (psd and active clay content)
   - Water Component (dispersive properties)

2. Recognise that clay containing tailings can mimic cohesive or non-cohesive properties depending on water chemistry

3. Believe that this understanding can fill a fundamental gap in TSF design and safety