Geochemical & Physical Weathering of Acid Generating Rock - Implications for Long-Term Stability of Mine Slopes and Waste Dumps

Dr. A. MacG. Robertson and Ms. S. Shaw

Robertson GeoConsultants Inc.
Suite 640, 580 Hornby Street
Vancouver, BC Canada
arobertson@infomine.com

Stability of Mine Rock Slopes

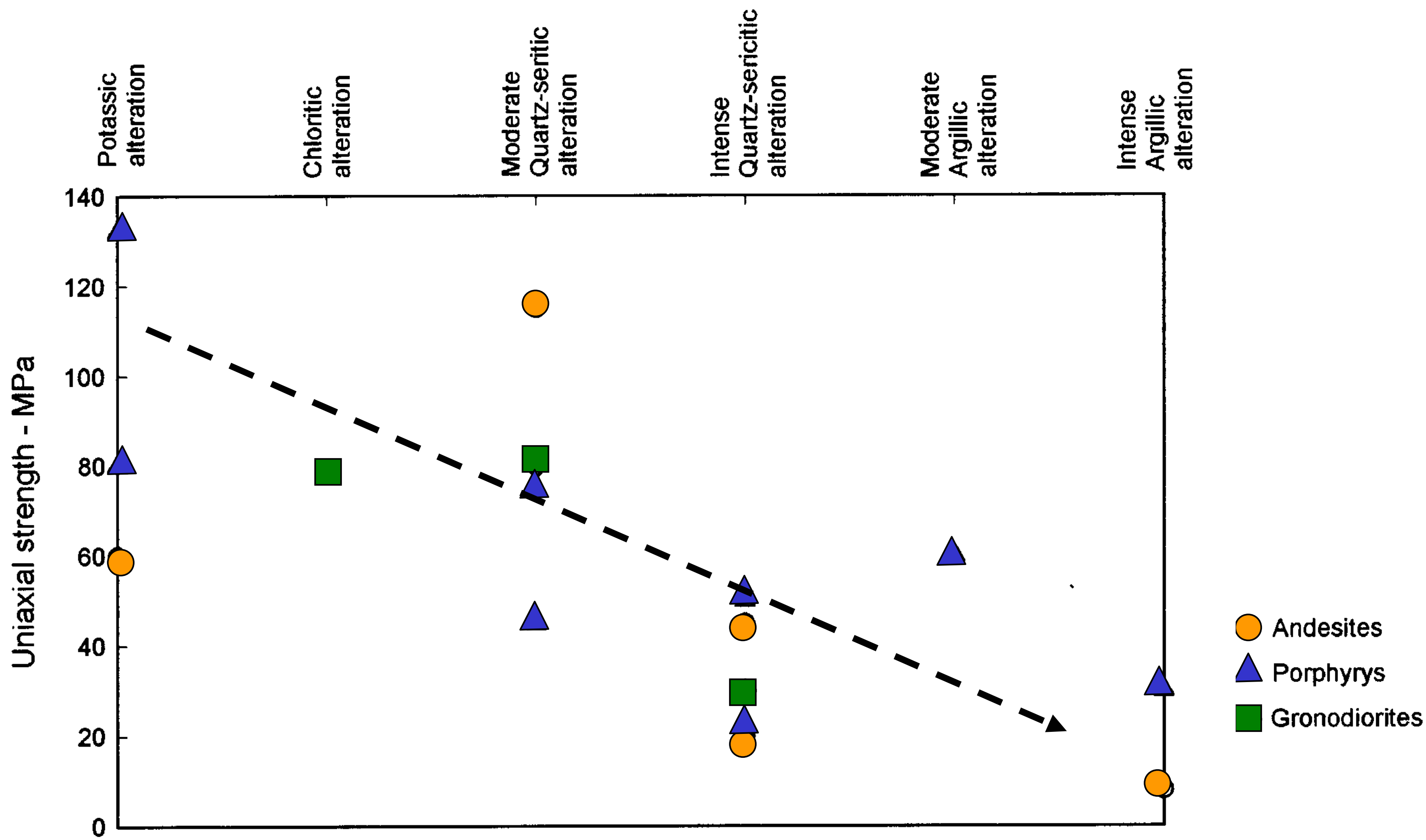
Mine rock piles placed at their angle of repose for the fresh mined rock have an intrinsic stability at the time of placement. The conditions determining stability may change with time as a result of time dependent **changes in the strengths** along potential failure surfaces **and the forces**, principally water pressures, acting on these potential failure surfaces.

Weathering

- The time dependant change in geotechnical characteristics of a rock results from:
  - **Physical Weathering** - e.g. thermal expansion and contraction, abrasion, salt and ice crystal growth; slaking due clay mineral expansion and contraction during wetting and drying; crushing of contact points during stress re-adjustment:
  - **Chemical Weathering** - e.g. geothermal alteration; oxidation; hydrolysis; dissolution; diffusion; and precipitation
- These weathering processes may result in an increase or a decrease in rock strength, and an increase or decrease in permeability

Pre-mining Alteration

- The **natural geothermal processes** that are associated with sulphide ore genesis alter alumino-silicate minerals in the rock mass.
- Sericite-clay and chlorite-epidote altered zones surrounding such ore bodies **often exhibit reduced strength properties and an increased propensity to slake** when exposed to air and water.
- Additional alteration occurs as a consequence of exposure of the mineral deposits to air and water and the resulting oxidation of pyrite and further hydrolysis of the aluminosilicates.



Relationship between intact rock strength and degree of alteration.
(Reference: Hoek, Read, Karzulovic and Chen (2000))

Mineral Alteration

- Under non-acidic conditions, primary minerals like feldspars weather to form clay and amorphous hydroxide minerals, such as kaolinite and gibbsite
- Under acidic and sulphate-rich conditions, produced by pyrite oxidation, aluminosilicates weather far more rapidly. Aluminum is highly soluble under these conditions.
- Acid leaching is concentrated on weak zones such as fractures in rock particles and mineral cleavages causing a breakdown of the rock fabric.
- When this occurs over natural sulphide bodies it results in the production of gossan or oxide zones, often with high percentages of clays, including smectite clays.

Consequence of Mining Pyritic Rock

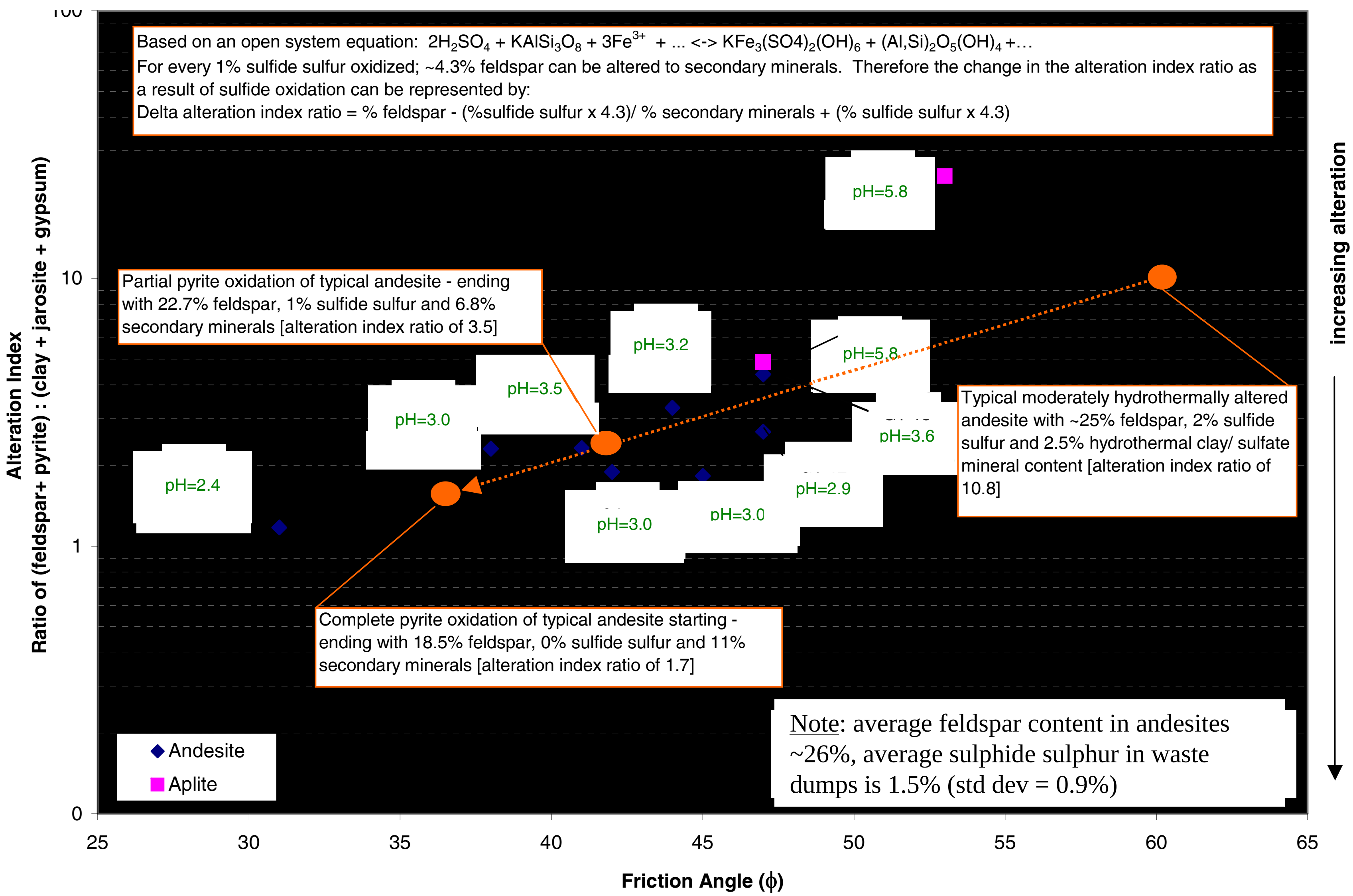
- **Mining** of altered and acid-generating sulphide containing waste rock **increases, by several orders of magnitude**, the surface area of rock surface exposed to air and water resulting in hugely increased rates of slaking (**physical weathering**) **as well as geochemical weathering**.
- Hydrolysis, fragmentation and breakdown of the rock fabric, results in an increase in the percentage of fines, including clays.
- Precipitation, when it occurs, may result in temporary or durable cementation.
- This in turn **results in changes in both the permeability and shear strength of the mine rock**

Oxidation Products Mass Balance

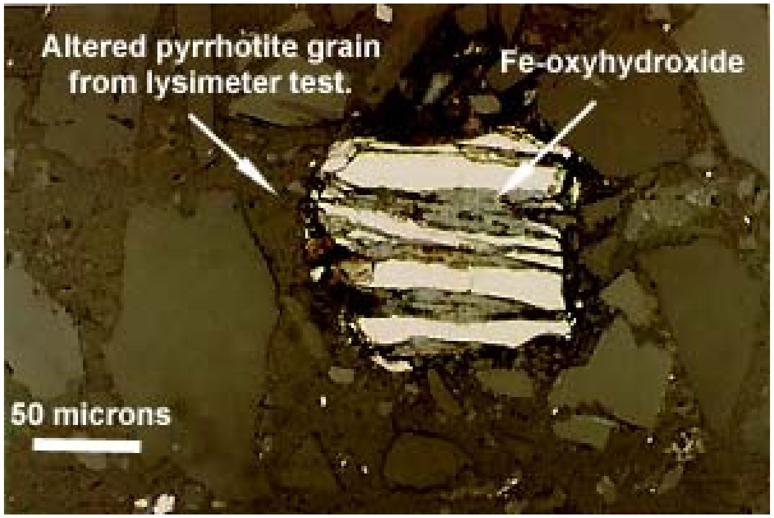
1% by weight of sulphide sulphur can produce:

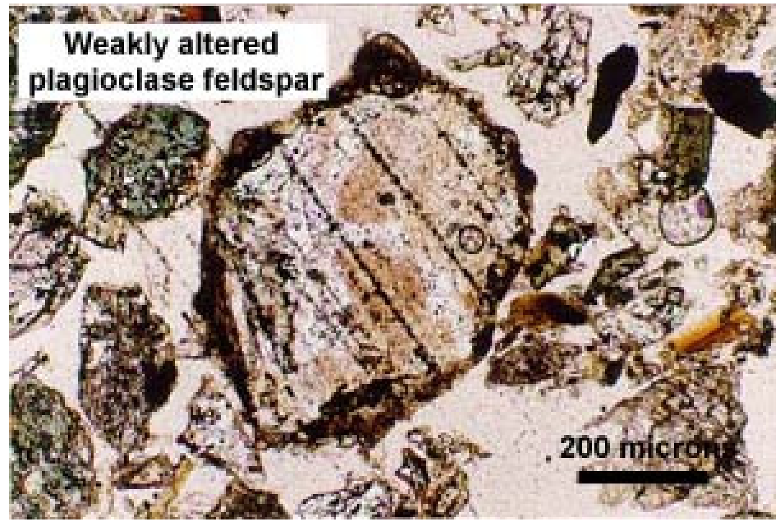
3.2% by weight of sulphuric acid and this can hydrolyze
4.3% by weight of Feldspar to secondary minerals such as clays and jarosites.

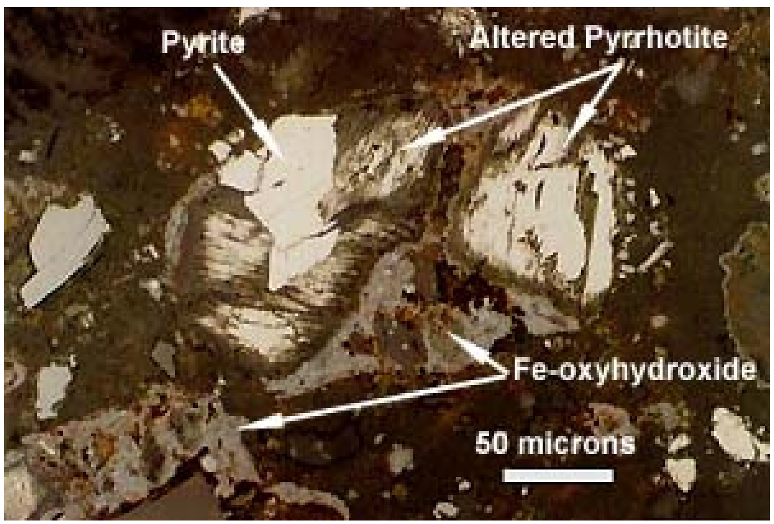
The sulphur in rock containing 5% by weight sulphide sulphur can hydrolyze up to 430 lbs/ton (21.5%) of mine rock.



Robertson GeoConsultants Inc.
Mining, Geotechnical and Environmental Engineers


Altered pyrrhotite grain from lysimeter test.
Fe-oxyhydroxide
50 microns


Weakly altered plagioclase feldspar
200 microns


Pyrite
Altered Pyrrhotite
Fe-oxyhydroxide
50 microns


Altered biotite grain
50 microns

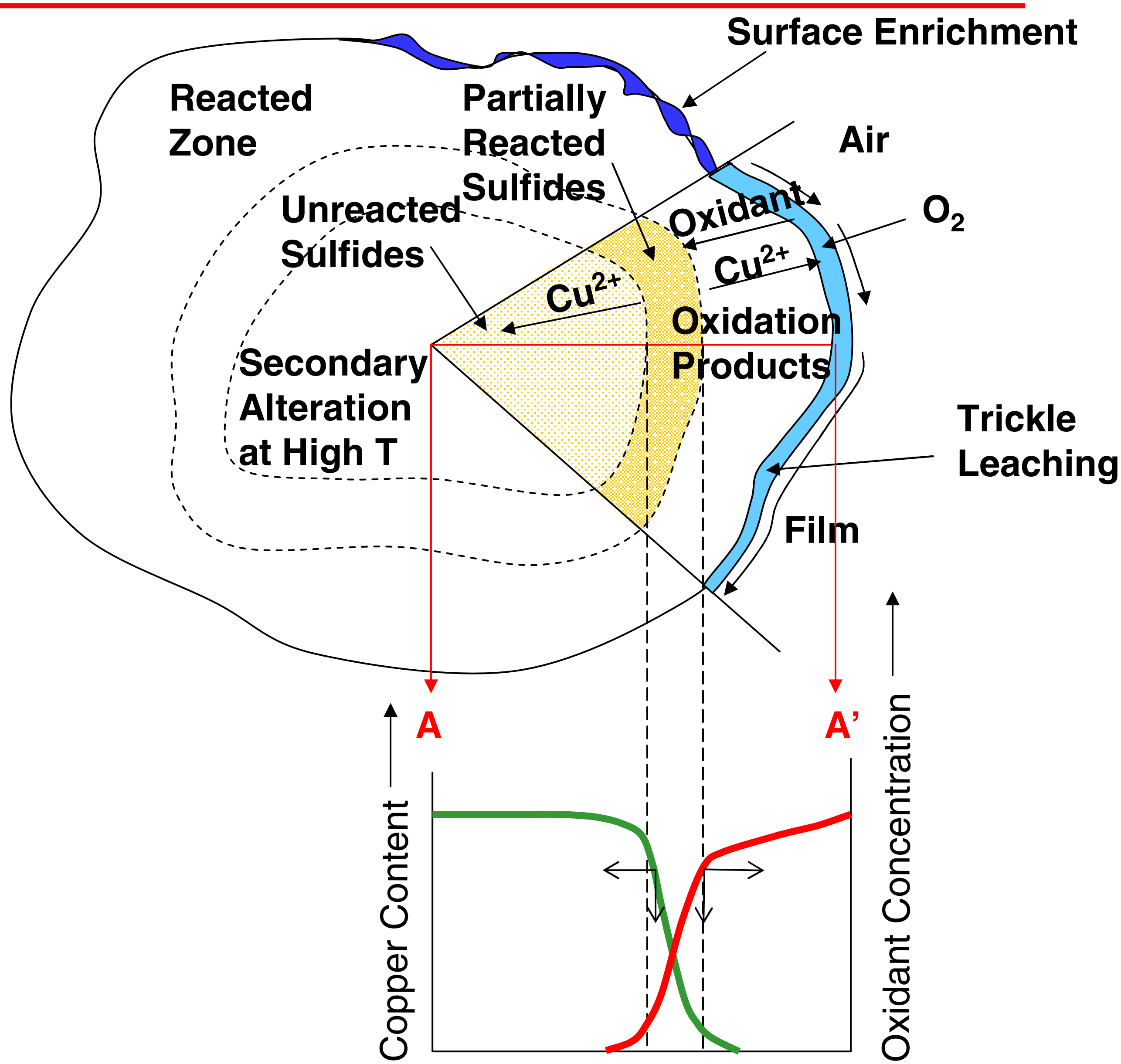
Knowledge from Cu Heap Leaching

"The acid in the leach liquor attacks gangue minerals in the region of the dump or heap were it is generated. The rates of attack depend on the local pH and vary among the numerous gangue minerals present…dump leach liquor pH typically ranges between pH 2.6 and 2.9.

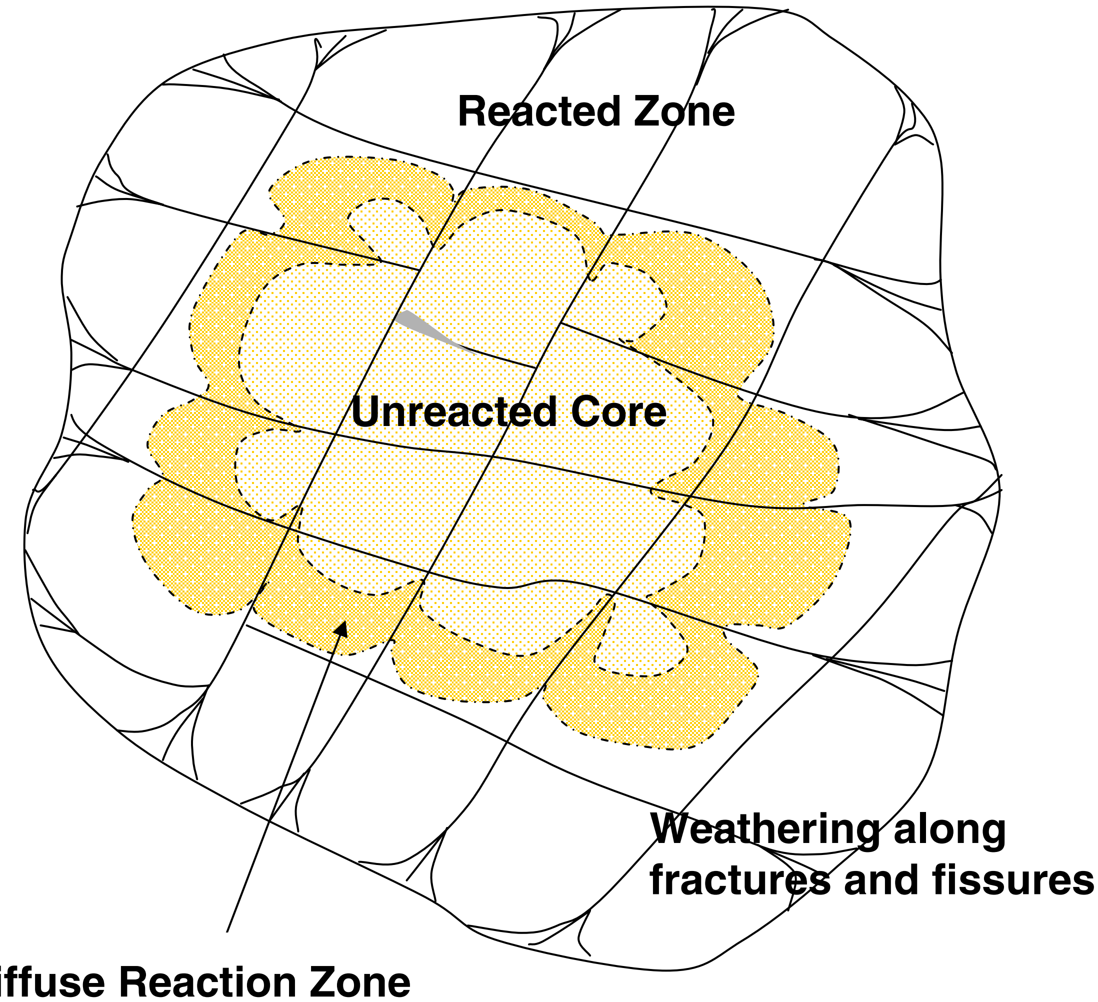
Acid attack of gangue minerals also causes rock decrepitating, meaning loss of rock physical integrity. Consequently the average rock particle size and permeability to both percolating leach solutions and air flow tends to decrease with extended leaching time.

New mine waste dumps are most often gray in color and have coarse, rock surfaces. Very old dumps, measured in leaching years, are stained yellow from jarosite and often weathered to a smooth, near soil, surface texture." (Bartlett, 1998)

Sulfide ore fragment showing reaction zone, shrinking unreacted core and expanding rim (reacted zone). After Bartlett, 1998.



Ore fragment after extensive chemical weathering along fissures due to internally generated acid from pyrite oxidation After Bartlett, 1998.



"The rock leaching kinetics are complicated by changing microporosity, pH, solution concentrations of several species, and chemical weathering and disintegration of the rocks by the generated sulfuric acid."

Robertson GeoConsultants Inc.
Mining, Geotechnical and Environmental Engineers

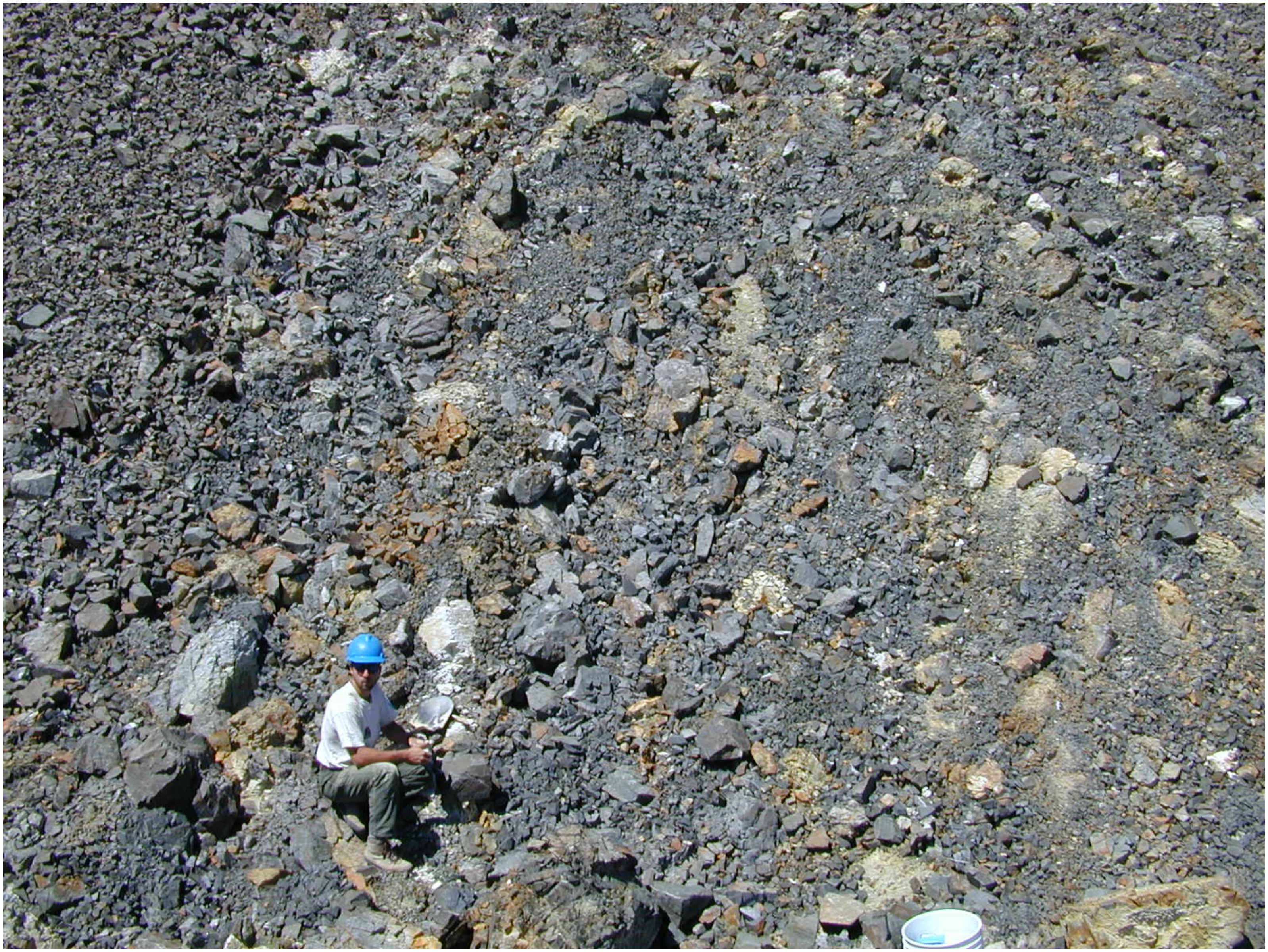
More Observations From Dump Leaching

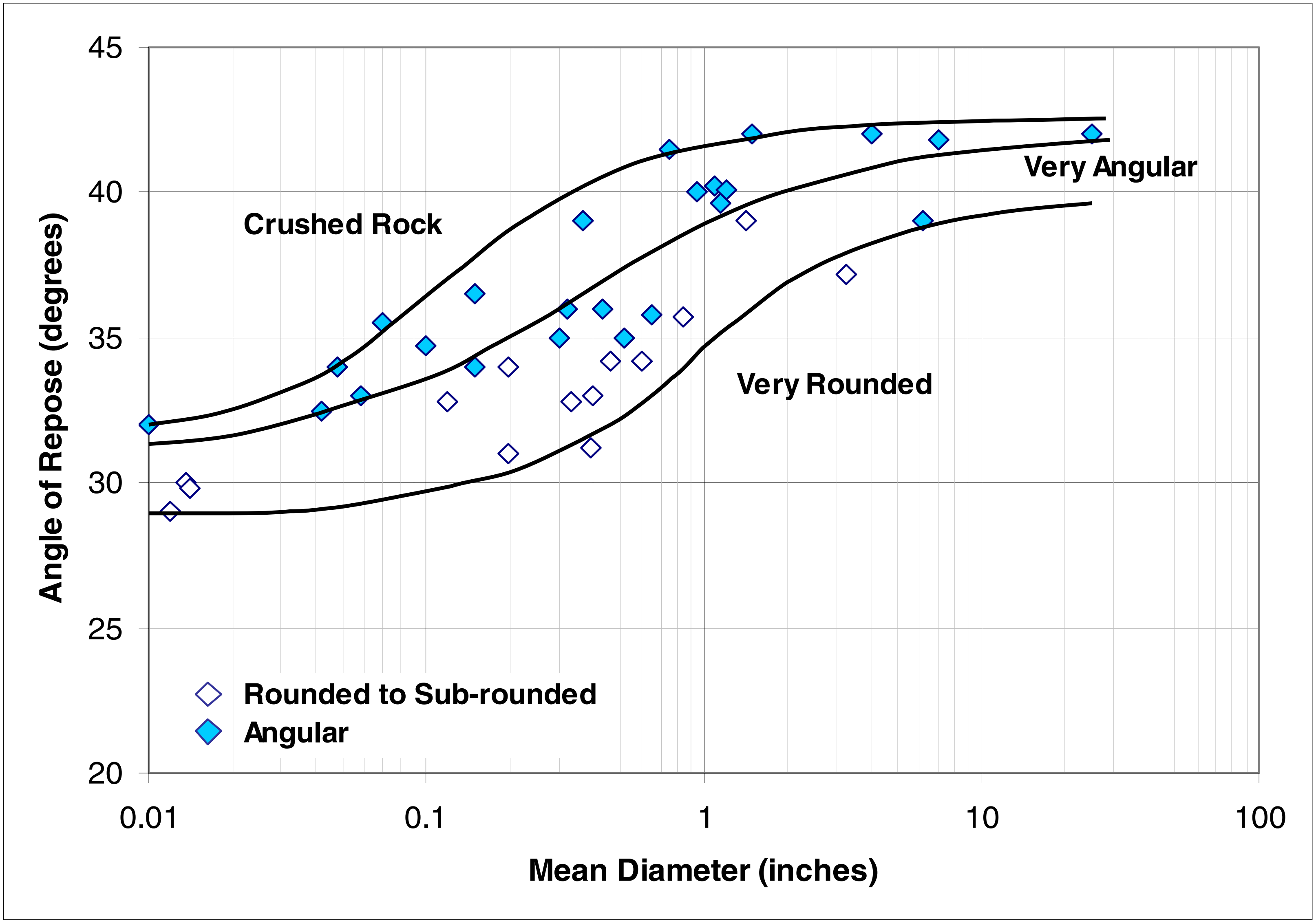
- The average rock particle size, and permeability to both percolating leach solutions and airflow, tends to decrease with extended leaching time.
- This is a major factor preventing adequate aeration and continued economic leaching as the mine dumps age.
- Basic igneous host rocks are generally less resistant to acid weathering and disintegration than more siliceous rocks
- Ores that contain clay, or minerals that weather to clay, rapidly lose permeability

Observations from Bingham Canyon Leach Dumps

- The acidic environment existing within waste dumps cause rapid breakdown of the intrusive rock into clay and claylike material
- Dumps containing large quantities of intrusive rocks increase in clay content and iron precipitate content and decrease in surface and interior permeability with time
- Debris flows result from the flow of water over the crest of waste dumps . The rate of waste movement is generally on the order of several hundred feet per hour
- Debris flows occur in old dumps having low surface and interior permeability due to the breakdown of intrusive rock and deposition of iron salts from leach solution

(Pernichele & Kahle, 1971)





(after Simons and Albertson, 1960)

Fresh Rock

↓

Weathered Rock

No Surface Attack

Partial Surface Attack

Pervasive Surface Attack

Knowledge from Coal Spoil Studies

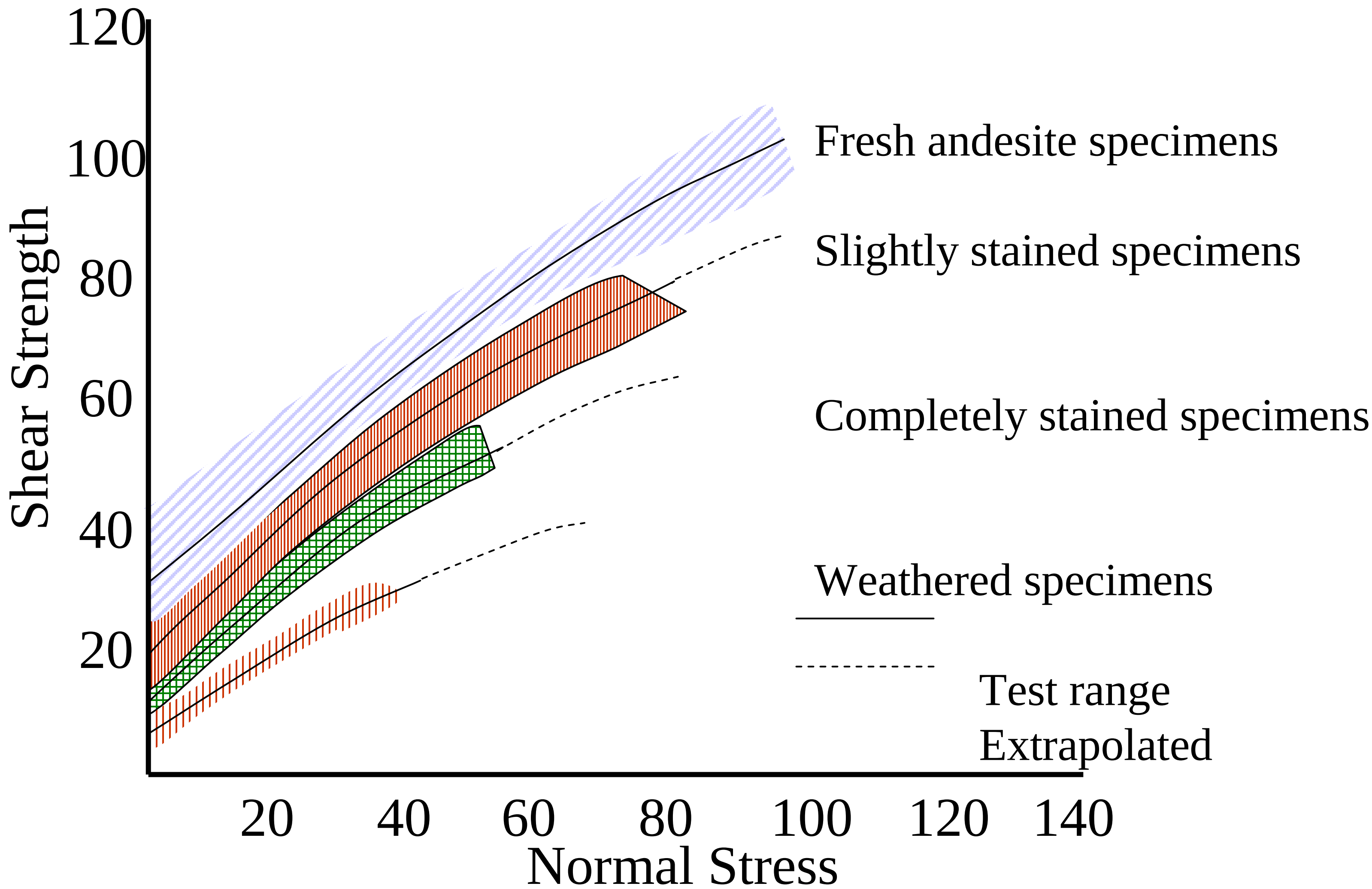
- The generation of clay size fines by physical weathering may reduce the friction angle by 2 or 3° (Seedsman and Emerson, 1985). This reduction does not occur gradually, as the clay fraction increases, but relatively suddenly, at a clay content of about 10%. At this clay content, the larger particles in the spoil are no longer in direct contact which each other, but tend to be supported in a matrix of clay-sized particles. The weathering may occur at the surface of the spoil piles to a relatively shallow depth, or deep within the spoil piles due to a fluctuating water table.
- Chemical weathering reduces the friction angle by 6 to 12°, and is a long-term process (Taylor and Spears, 1970; Taylor, 1984).

Observations From Natural Slopes

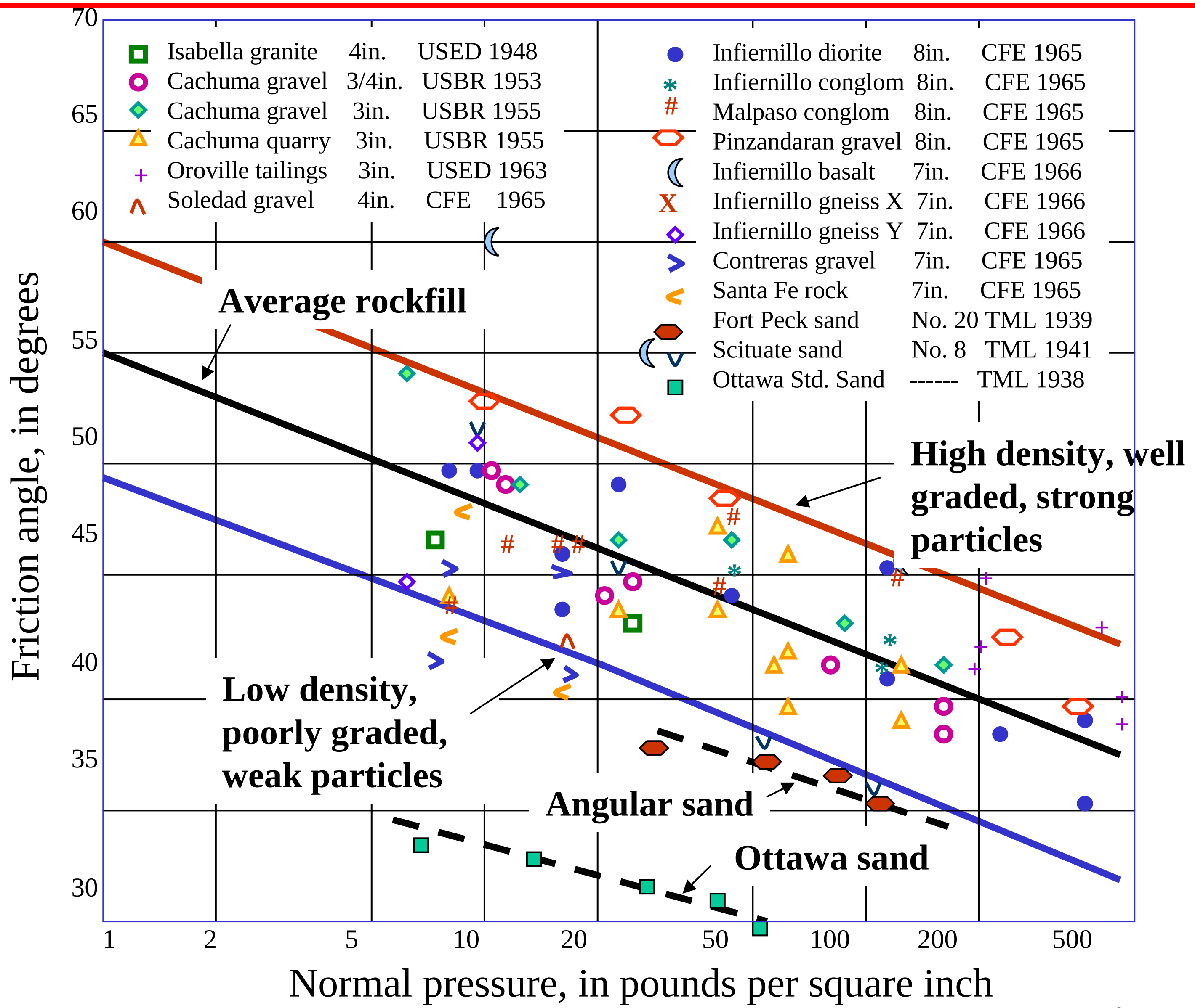
In addition to the general mechanical properties, a remarkable strength loss at the dissociation front, and the increase of smectite at the oxidation front of mudstone, could lead to the generation of landslides. Indeed, landslides with sliding surfaces along or beneath the oxidation front are quite common in mudstone areas. ----- these rocks weather very rapidly if the environment is artificially changed.

Chigira and Oyama (1999)

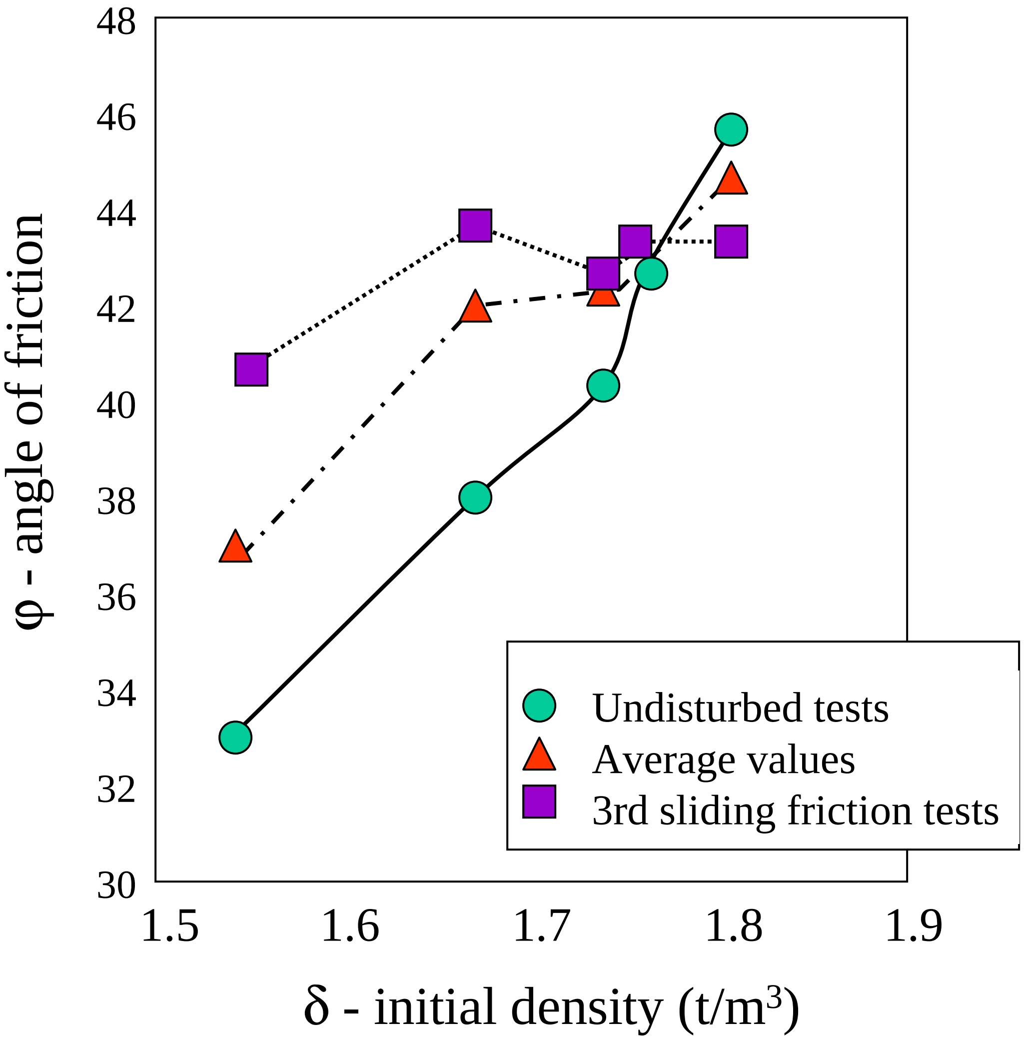

RGC
0270
2



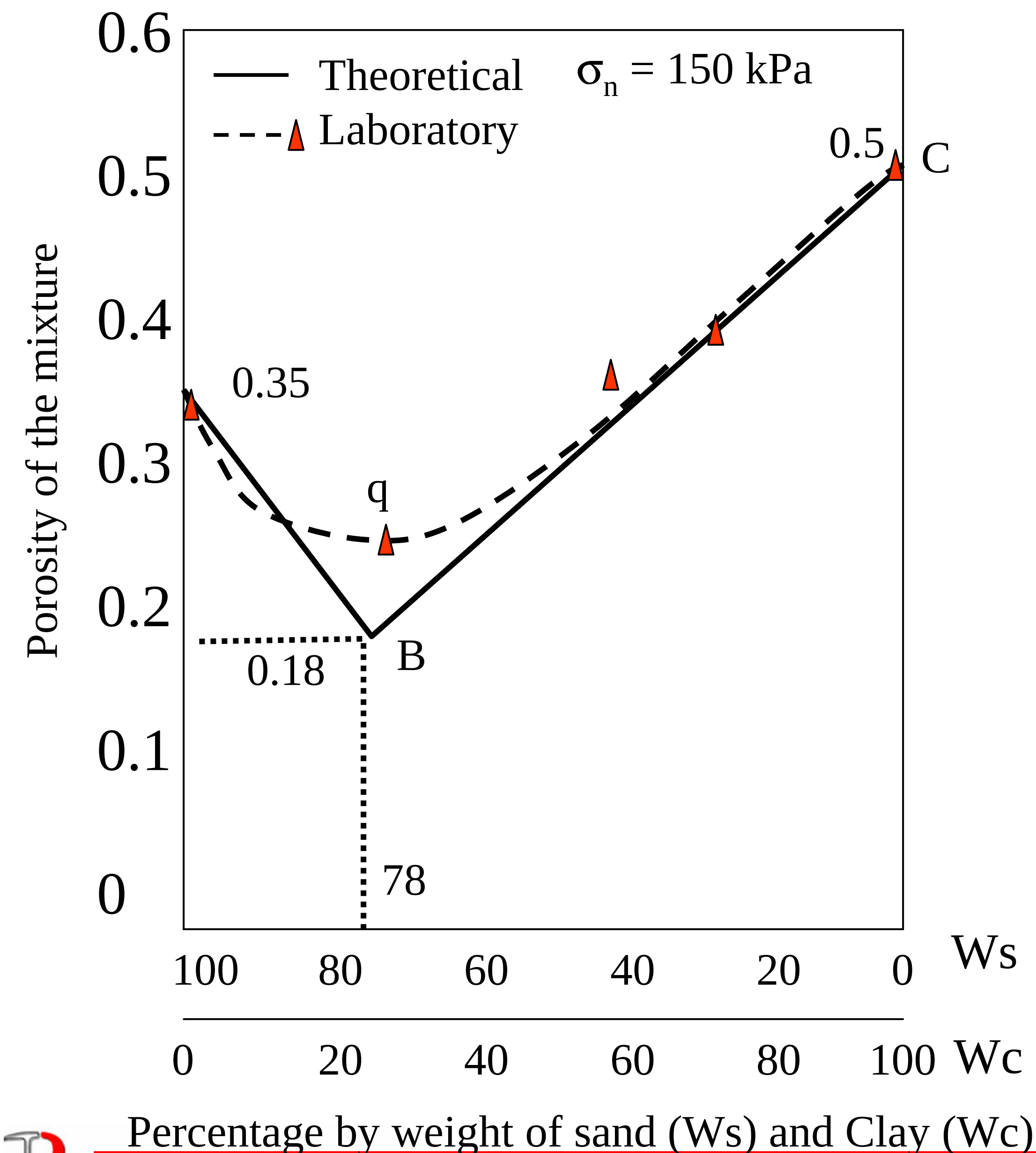
Triaxial test results - weathered Ankara andesites (after Pasamehmetoglu et al., 1981)



Ref: Lepps, 1970

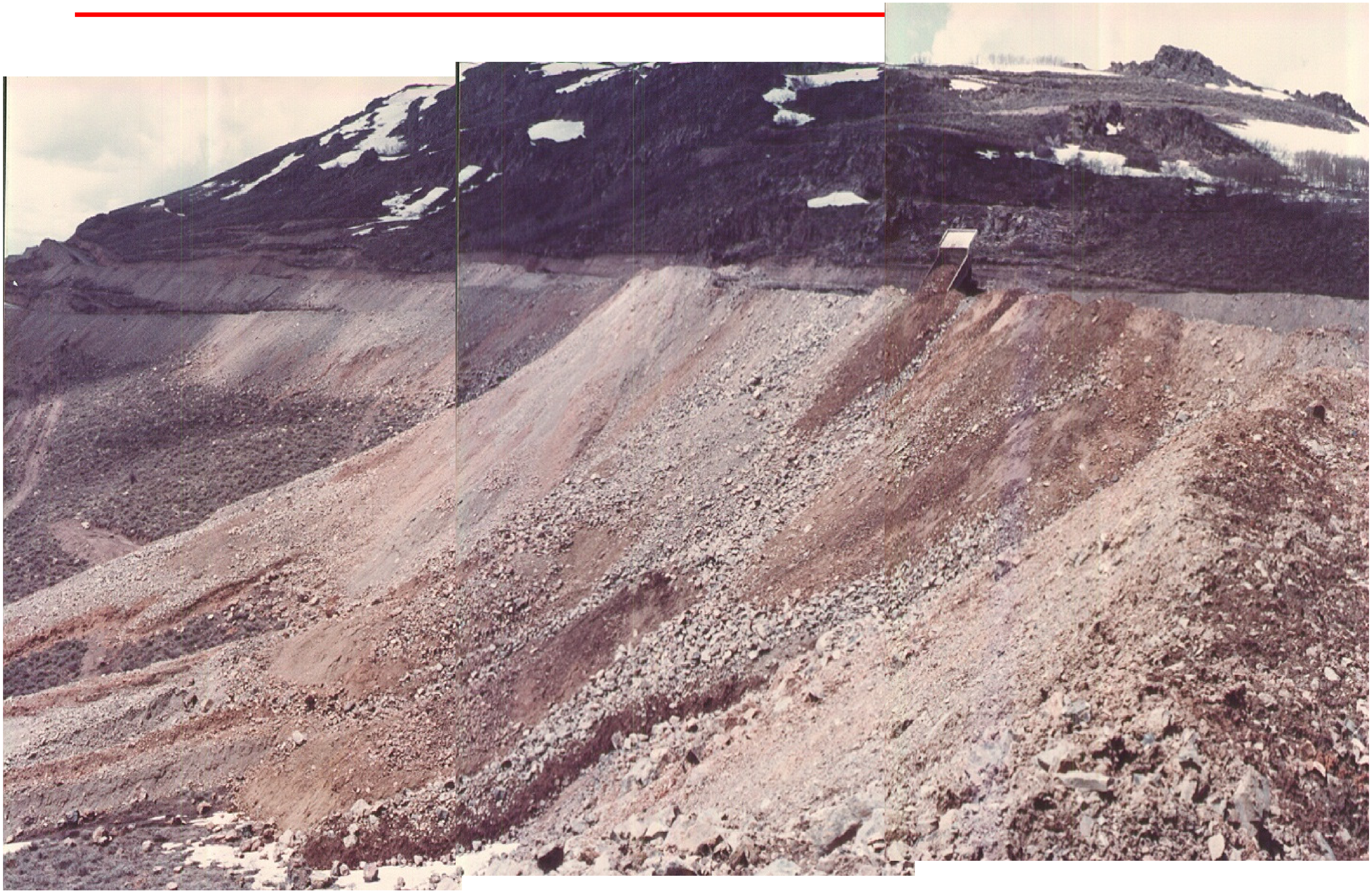


Reference: Nieble, Silveira and Midea, 1974



Changes in porosity of the sand-clay mixtures

Ref: Vallejo and Mawby, 2000



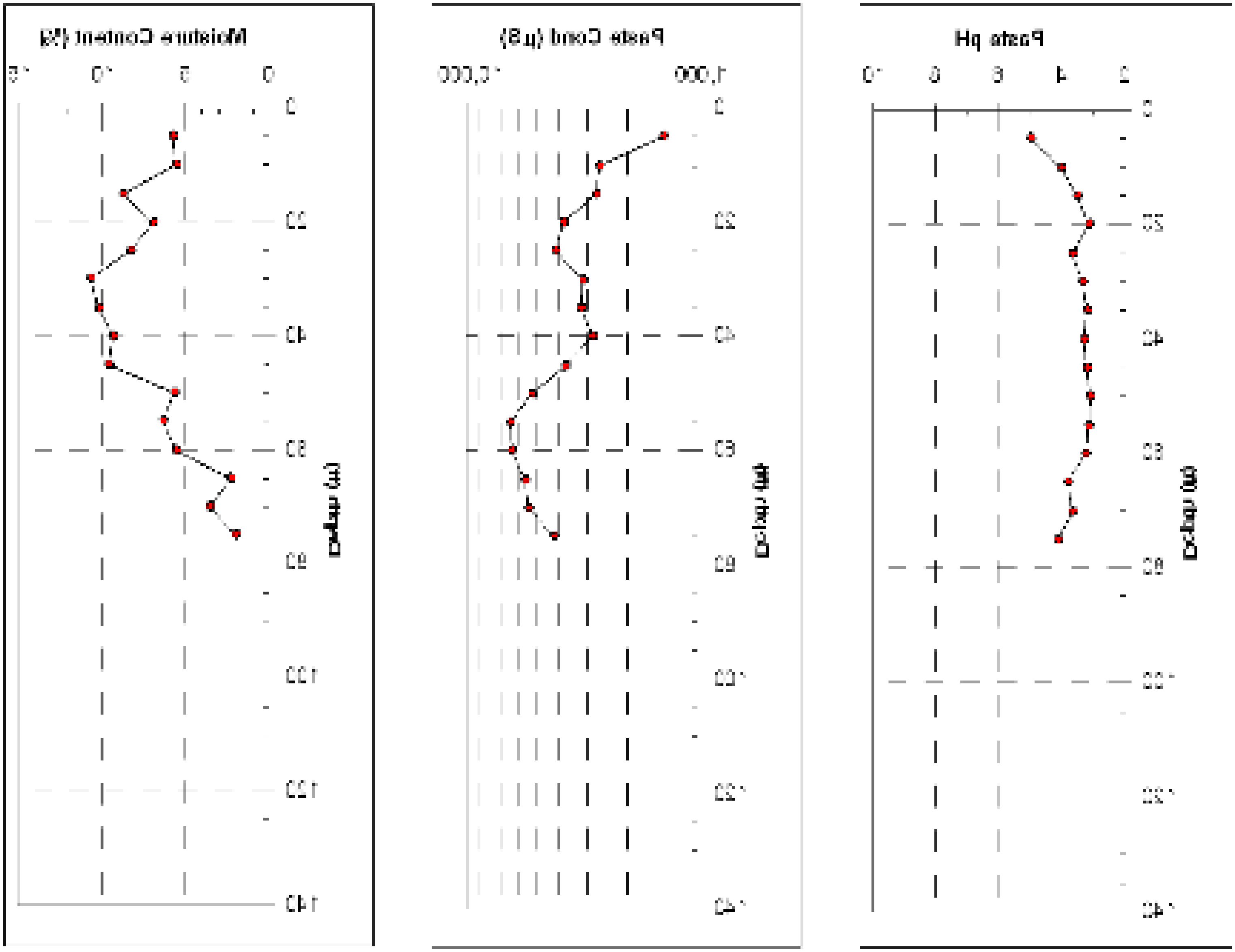
Two failures with run-outs observed extending from toe of rock pile.

View of run-out tongues showing coarse nature of most mine rock.

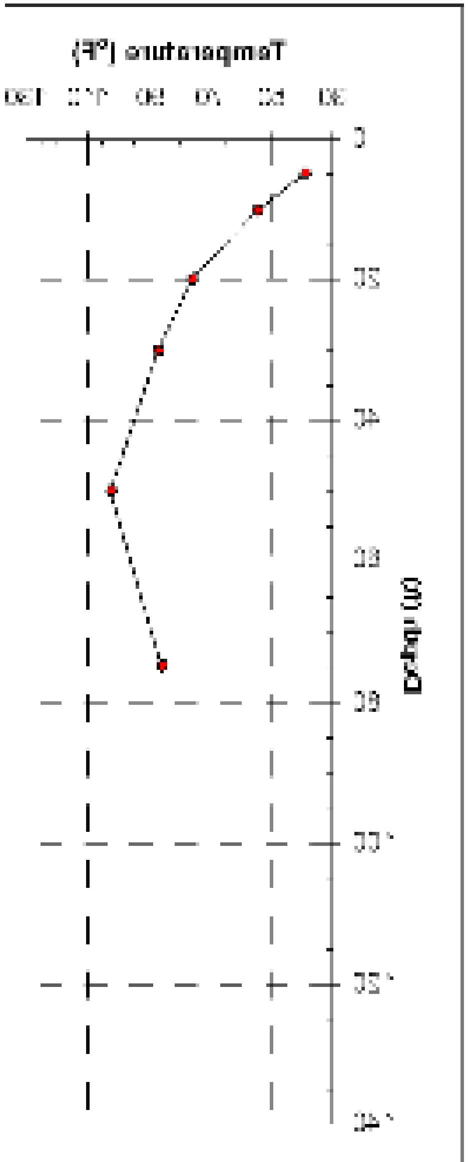

8. 28. 2000

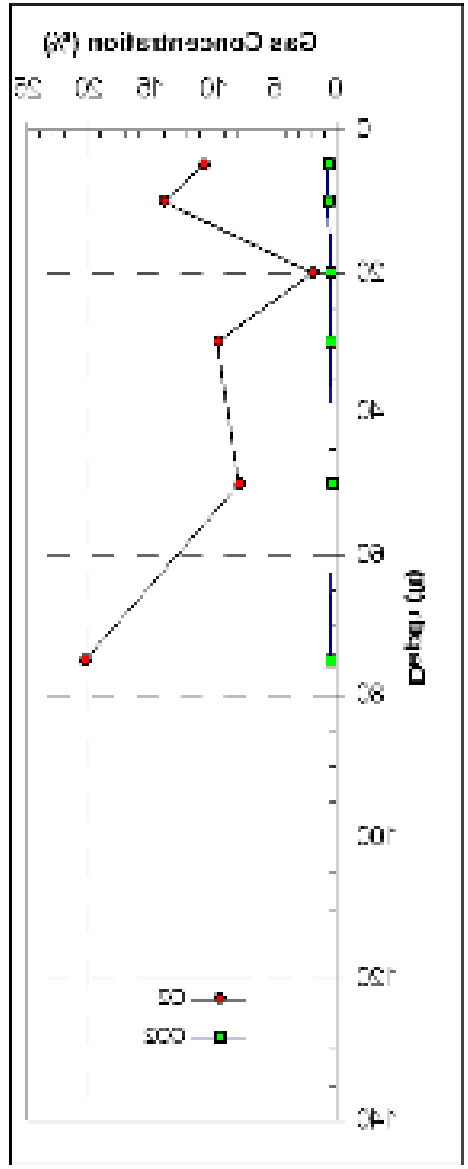

Paste pH = 2.2
9/17/00


9/17/00



Characterization & Monitoring Data

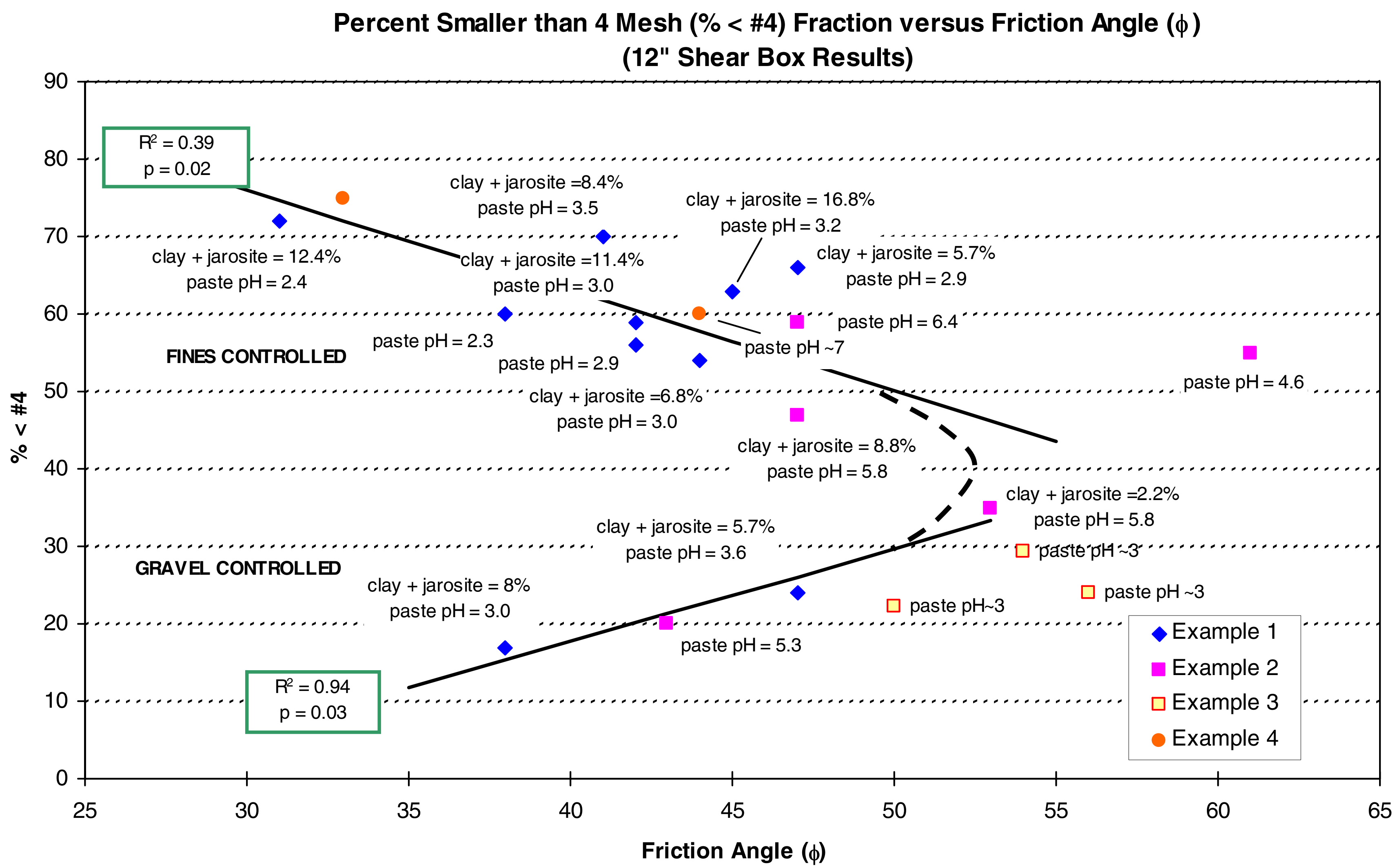




Characterization & Monitoring Data

Representative Water Quality for Examples on Next Plot

	Example 1	Example 2	Example 3
pH	2.7	3.5	2.2
SO_4	17,600	1,000	30,000
Al	1800	42	1500
Fe	800	2.5	950
Cu	8.5	0.2	80
Zn	141	5.1	30



Robertson GeoConsultants Inc.
Mining, Geotechnical and Environmental Engineers