The MEND Minewall Technique: Overview and Details

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Overview of the Minewall Technique

- The Canadian MEND Program decided to standardize various "wall washing" procedures, and create a formal standardized technique for predicting the effects of mine walls on water in open pit and underground mines.

- Minewall 1.0 technique and simulation software was released in 1990, based on a short study of the Equity Silver pit in British Columbia (Morin, 1990, BCAMD report 1.15).

- The greatly expanded Minewall 2.0 was released by MEND in 1995 and included a Literature Review, User's Guide, Programmer's Guide, and Application to Three Open-Pit Mines (Morin and Hutt, 1995, MEND reports 1.15.2).

Overview of the Minewall Technique

- Minewall 2.0 was written in Visual Basic. It was basically a “compartmental” model that kept track of, during discrete time steps,
  - all inflows to the mine,
  - all outflows,
  - the water level within the underground or open-pit mine, and
  - mass-balance chemistry associated with all inflows, outflows, and the mine. The mass-balance chemistry within the mine could then be altered based on geochemical processes like kinetics and mineral precipitation-dissolution.

- If Minewall 2.0 were written today, it would probably be written as an add-on to a spreadsheet application, like Excel. However, most geochemical processes would still be handled as links to separate applications like MINTEQ.

Overview of the Minewall Technique

- The conceptual models for underground mines were based on work done in the 1960's and early 1970's by the Ohio University
  - Morth et al., 1972, Pyrite Systems: A Mathematical Model, Contract Report for the U.S. Environmental Protection Agency, EPA-R2-72-002

    (Footnote: a highly recommended read, illustrating how much good work had been done on ML/ARD in underground mines and on sulphide oxidation in general by the early 1970's; watch for some mathematical errors and early evidence that Singer and Stumm were wrong about major bacterial acceleration of sulphide oxidation.)
- The conceptual models for open pits in Minewall 2.0 were adapted from the underground models.
- Therefore, the general understanding and the ability to predict the geochemical effects of mine walls on mine water have been available at least since the 1960's.

Overview of the Minewall Technique

- Morth et al. (1972) described various field and kinetic tests from the 1960’s for obtaining unit-area and unit-weight reaction rates.
- Field tests in the 1960’s included isolation of portions of underground-mine walls and rinsing them periodically to obtain unit-area rates.
- Laboratory tests in the 1960’s included rinsing of blocks of rock, as well as standard “Sobek” (well-rinsed) humidity cells which can be traced back to at least 1962.
  - Hanna and Brant. 1962. Stratigraphic relations to acid mine water production. IN: 17th Purdue Industrial Waste Conference, p. 476-492. Purdue University.

Overview of the Minewall Technique

- Morth et al. identified three types of leaching from underground-mine walls:

  - migration of condensation carrying dissolved solids, originating from moist air in underground mines and the hygroscopic nature of concentrated acidic solutions around pyrite (labelled “diffuse leaching”)

  - unsaturated flushing of rock surfaces by trickling water (“trickle leaching”), and

  - saturated flushing of channels by inundation of the channel, temporarily halting oxidation (“inundation leaching”)

Overview of the Minewall Technique

- These three types of leaching can be simplified into:
  - Regularly
  - Periodically, such as by storms or snow melt or rapid infiltration
  - Not until flooded, which is usually relevant only after closure.

The remainder of this presentation will focus on the geochemical effects of the mine walls, and not the other inputs like background groundwaters.

Let's Get Up Close and Personal with Mine Walls!!

Two Current Approaches for Estimating Geochemical Reaction Rates of Mine Walls

Current Approach #1: Unit-area geochemical reaction rates (mg/m^2/week) and concentrations (mg/L) from tabular surfaces, obtained from on-site Minewall stations. The rates are then applied to a total amount of reactive surface in m^2.

This approach also be used with boulders and coarse rock.

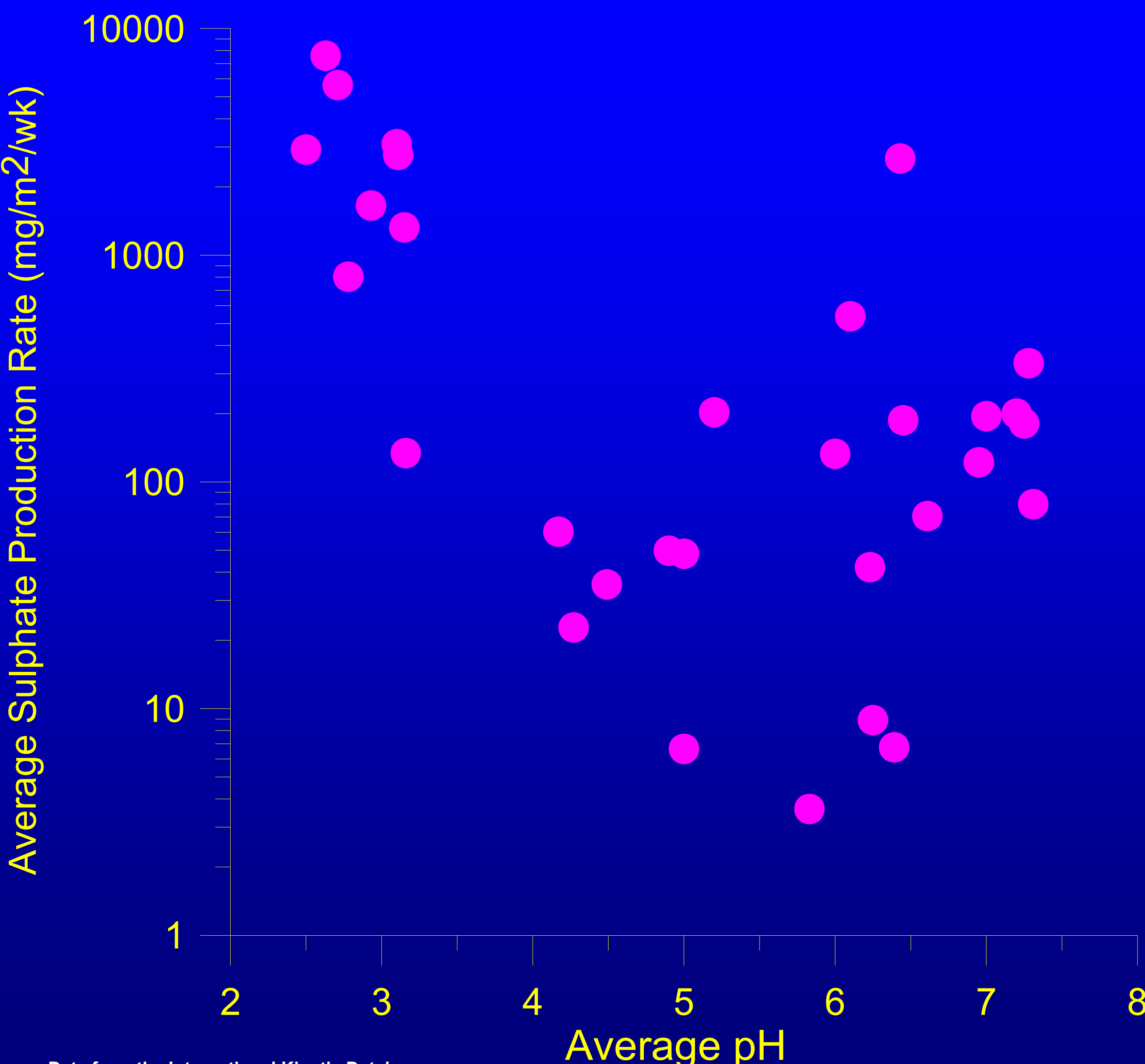
Two Current Approaches for Estimating Geochemical Reaction Rates of Mine Walls

Current Approach #2: Unit-weight geochemical reaction rates (mg/kg/wk) and concentrations (mg/L) from minus-1/4-inch crushed rock, obtained from laboratory humidity cells. The rates are then applied to a thickness of mine wall to obtain total kg.

Four Primary Steps in the Minewall Technique – Step #1

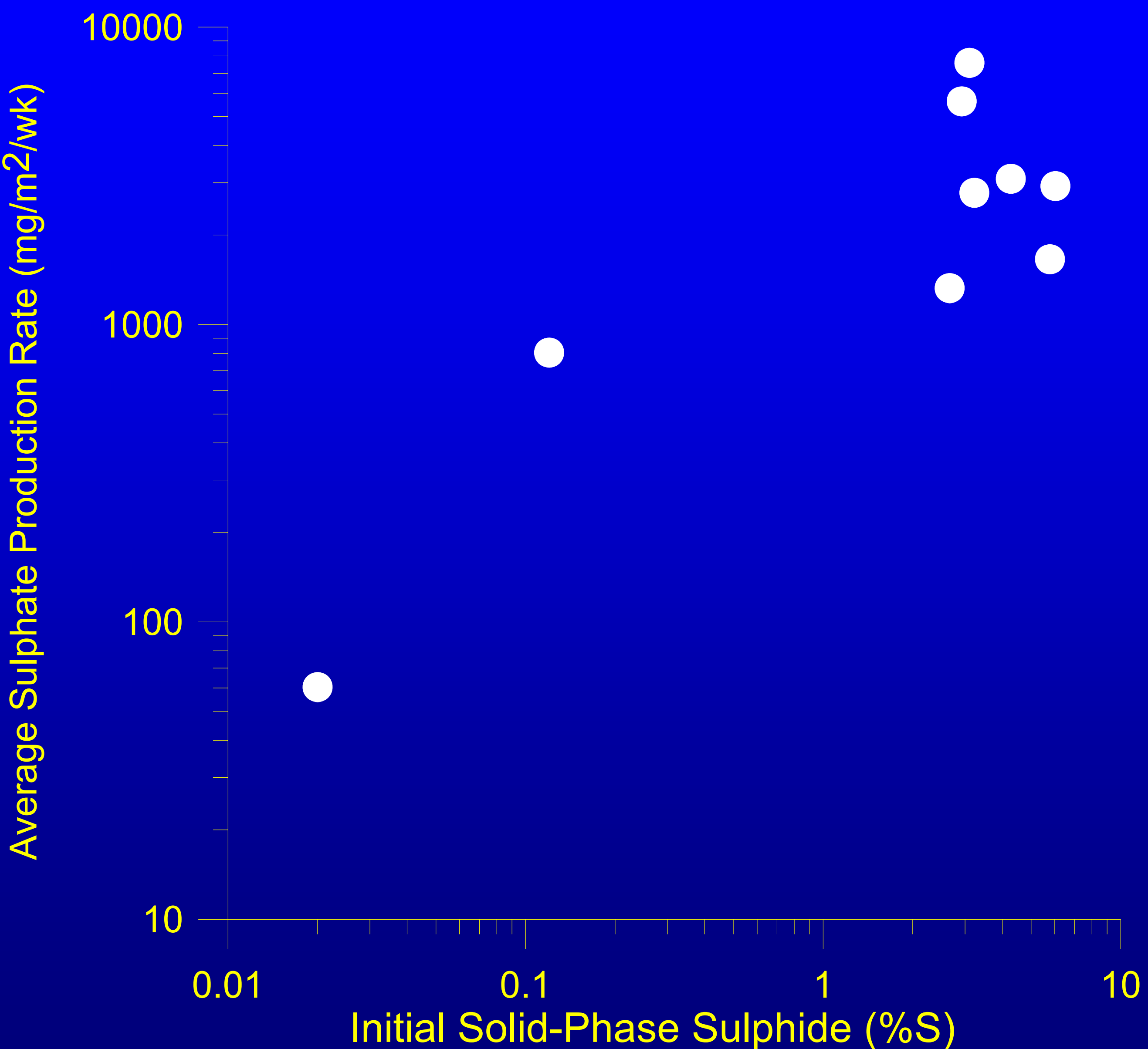
- First, obtain unit-area reaction rates. These can be obtained from Minewall Stations. Approximate unit-area rates can sometimes be roughly derived by mathematical conversion from unit-weight humidity cells

(discussed in more detail later).



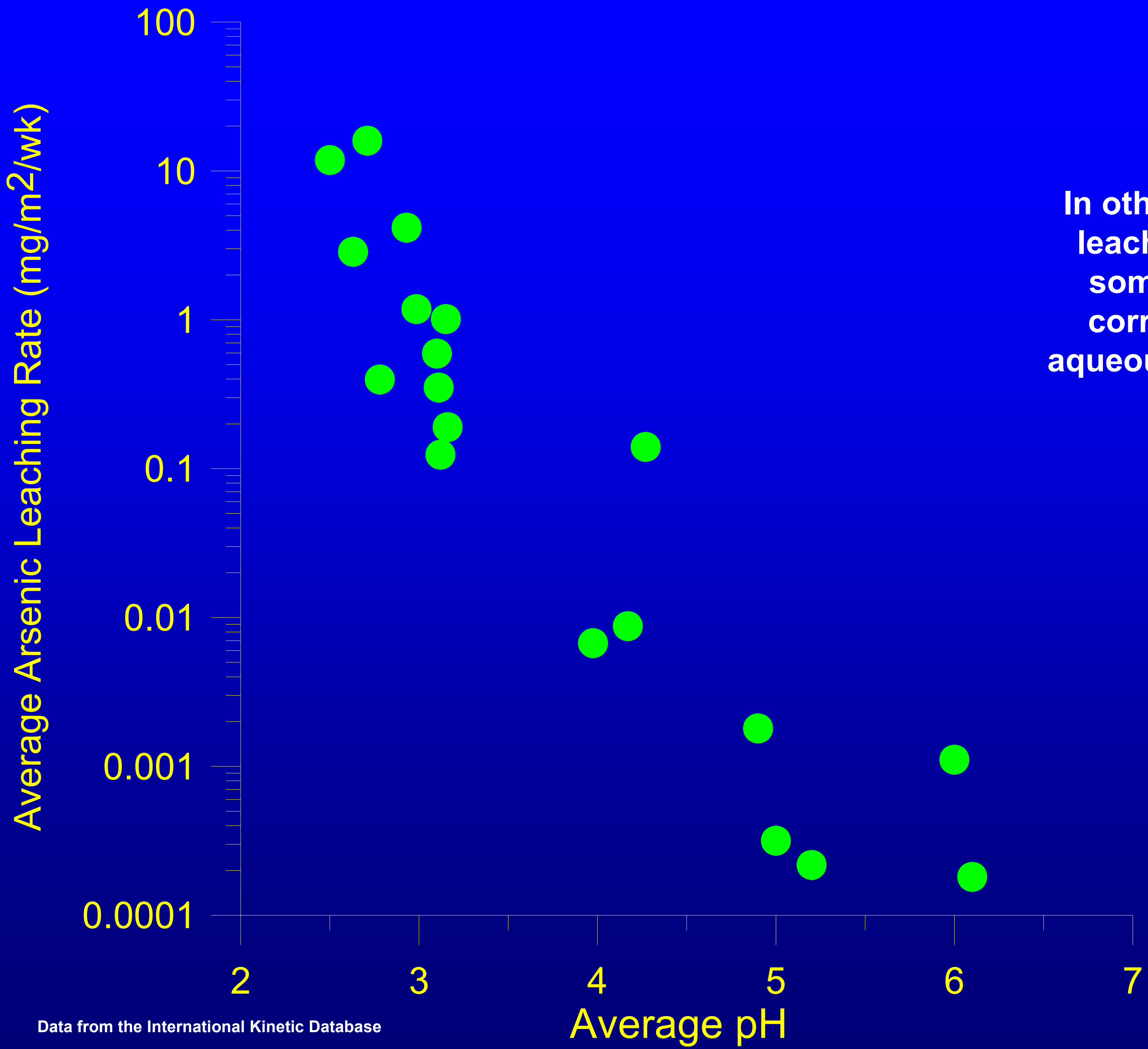
Data from the International Kinetic Database

For example, the International Kinetic Database contains Minewall-station data from several minesites. The compiled data (left) shows a large range in unit-area rates of sulphate production.



Pre-test ABA analyses for one site show the sulphate-production rate is partly dependent on the amount of solid-phase sulphide in the rock.

Data from the International Kinetic Database



In other cases, the leaching rates of some elements correlate better aqueous parameters like pH.

Data from the International Kinetic Database

Four Primary Steps in the Minewall Technique – Step #2

- Second, compile the lateral, inclined, and vertical exposed surface areas by elevation in the pit or underground workings, based on site-specific survey data.

Four Primary Steps in the Minewall Technique – Step #3

- Third, estimate the fracture intensity (existing or proposed mine) or design the blast intensity (proposed mine) in order to obtain a ratio of reactive surface area to exposed surface area, and include other rock surface like waste rock.

Reactive Surface Area – Step #3

- A first impression might be that the total reactive surface is equal to the exposed walls of a mine.

- However, fractures are invariably present in mine walls:
    - naturally,
    - by blasting and excavation.

They provide additional reactive surfaces.

- Morth et al. (1972) and Minewall field studies have found fractures that were oxidizing up to 15 m behind the visible mine wall.

Reactive Surface Area – Step #3

- As a numerical example, a pit wall that has (1) spacings for vertical and horizontal fractures of 1 meter and (2) oxidation occurring to 10 meters behind the wall will have 41 m^2 of reactive surface for each m^2 of exposed wall.

- For three Minewall case studies of pits, the average estimated ratio varied from 27:1 to 161:1, yielding total reactive surface areas of 11-240x10^6 m^2.

- When multiplied by their unit-area sulphate rates (as indicators of total acid generation), these pits were generating approximately 2-20x10^9 mg SO_4/wk (2-20 t/wk).

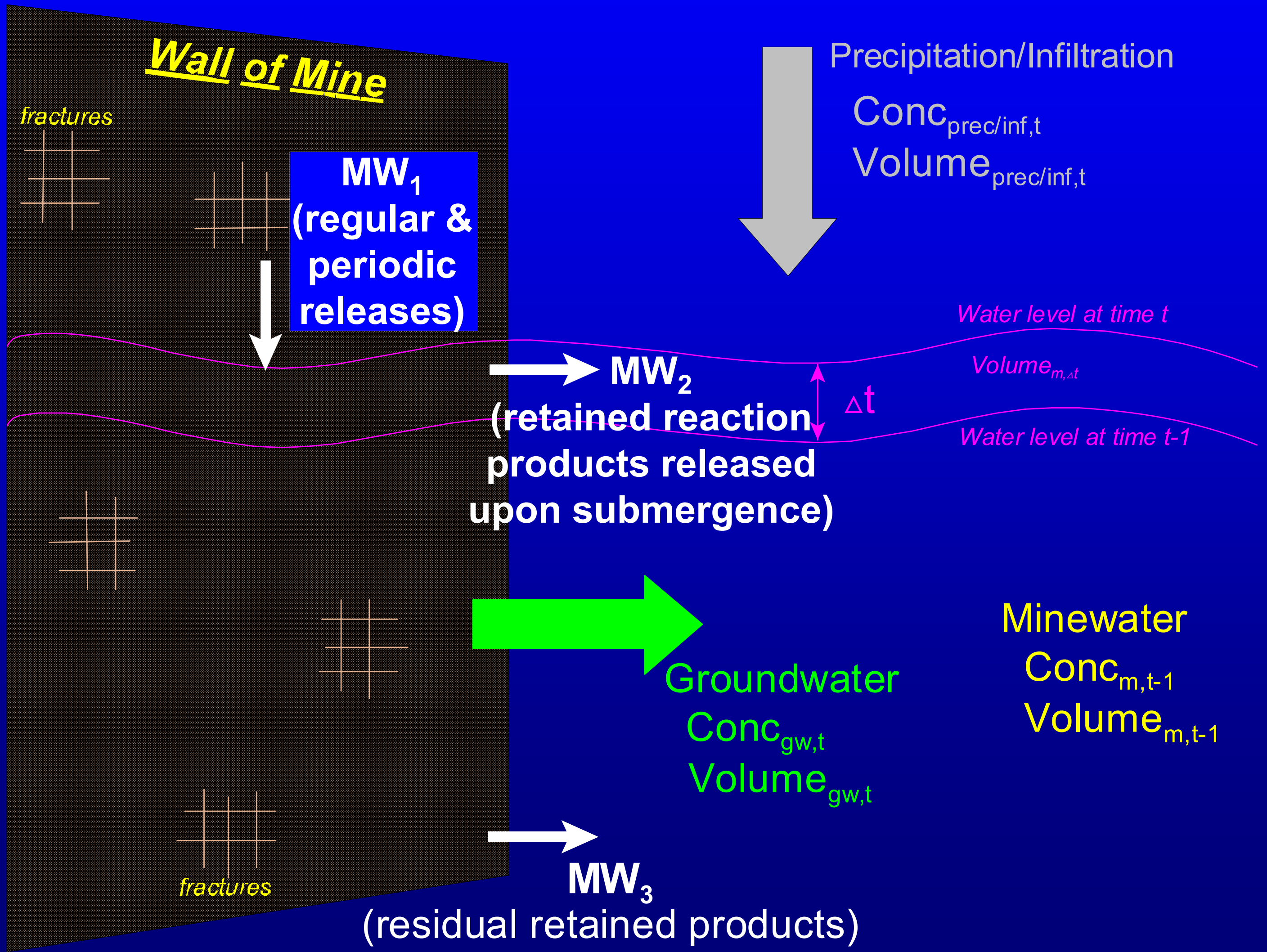
Reactive Surface Area – Step #3

- Any waste rock, ore rock, wall rock, tailings, or backfill placed in, or accumulating in, a pit or underground mine can add to this reactive surface area.

- For example, the Island Copper Pit contained $11.5x10^6$ t of waste rock at the end of mining, and its estimated rock-surface area rivalled that of the pit walls.

Four Primary Steps in the Minewall Technique – Step #4

- Fourth, estimate the loadings that will be released on a regular or periodic basis, or retained if/until that portion of the wall is submerged.



Released and Retained Loadings – Step #4

- Three case studies of open pits modelled with Minewall, calibrated to pre-existing monitoring data, indicated regular and periodic flushing was 20-35% of annual production from all reactive rock surfaces in the pits.

- This meant that 65-80% of annual production was being held within the pit walls and would be released only when/if the walls were submerged and only proportional to the amount of wall submerged over a particular time interval.

Interesting Detail #1:

How fast do mine walls weather and erode to expose fresh minerals?

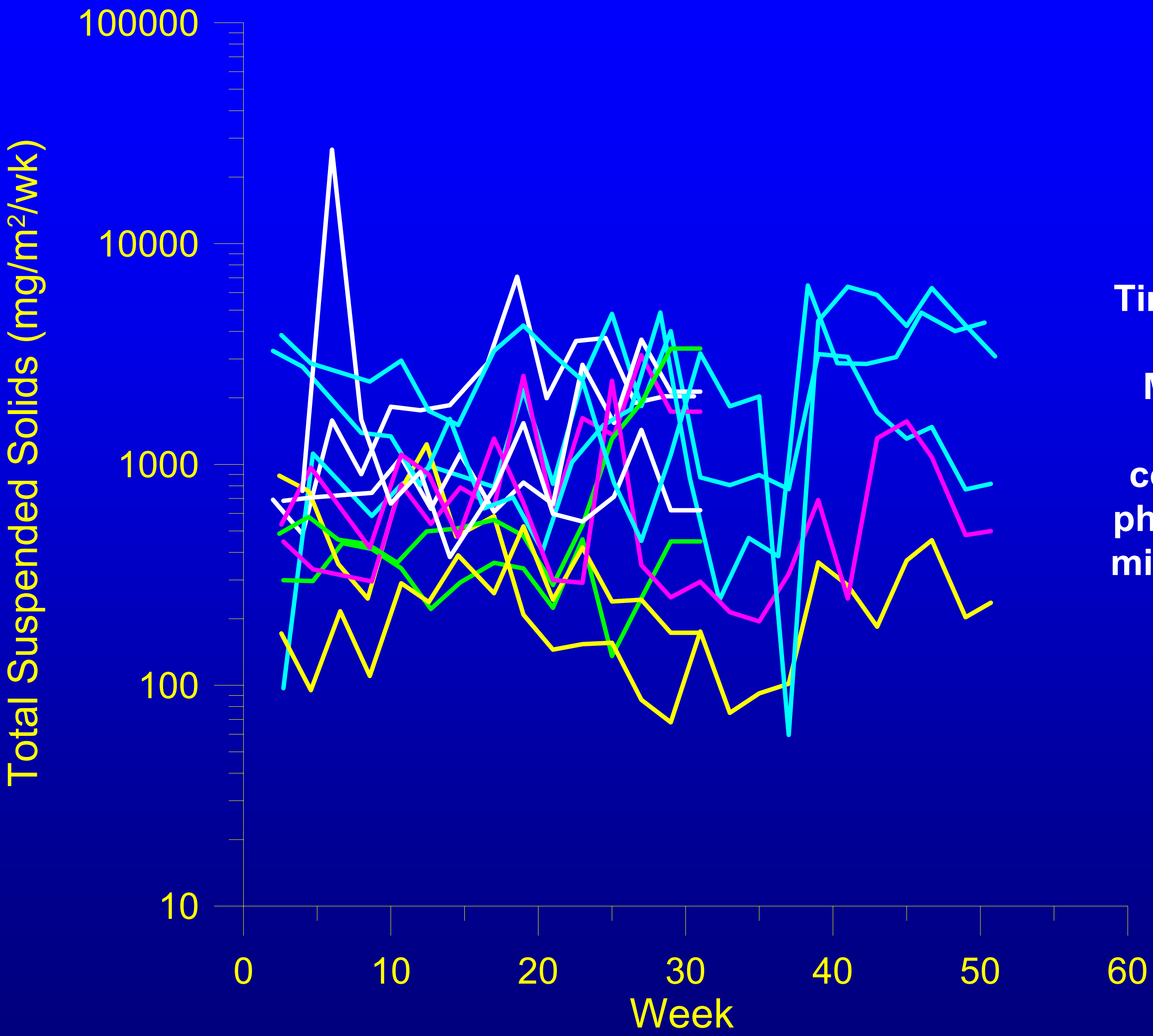
Detail #1: Erosion Rates of Mine Walls

- Because dissolved elements are detected in Minewall-station rinses, there are measurable rates of "chemical weathering".

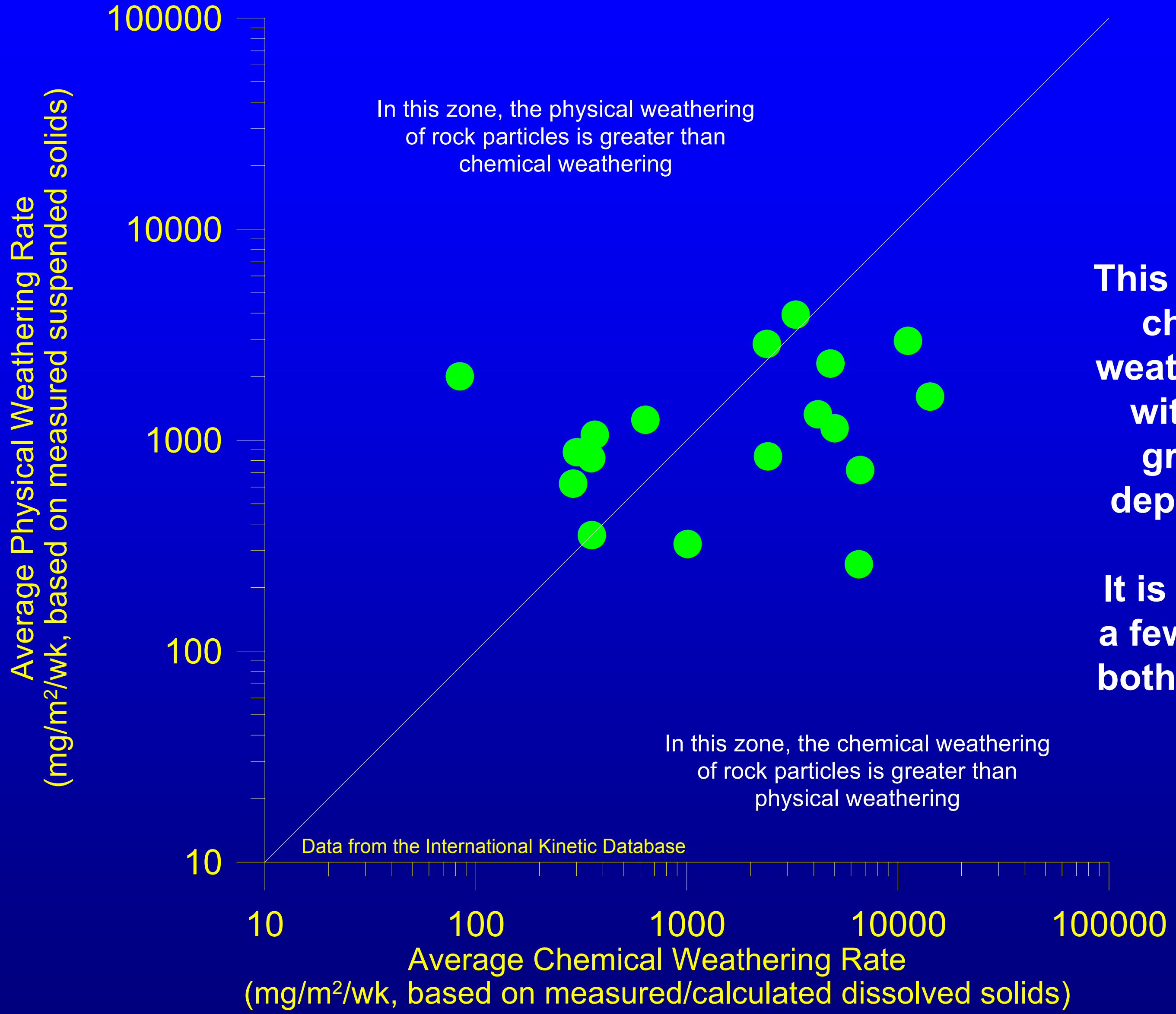
- Because total suspended solids are detected in Minewall-station rinses, there are measurable rates of "physical weathering".

- Research has shown that the oxidation of sulphide minerals produces secondary minerals with greater molar volumes (e.g., Jerz and Rimstidt, 2003). In effect, this causes mineral grains to "pop off" the walls, exposing fresh grains. So the concepts of (a) stable, persistent outer rinds reducing deeper oxidation, (b) the classic "shrinking core" model, and (c) eventual "burn out" of mine walls do not necessarily apply.

Jerz, J.K., and J.D. Rimstidt. 2003. Efflorescent iron sulfate minerals: Paragenesis, relative stability, and environmental impact. America Mineralogist, 88, p. 1919-1932.

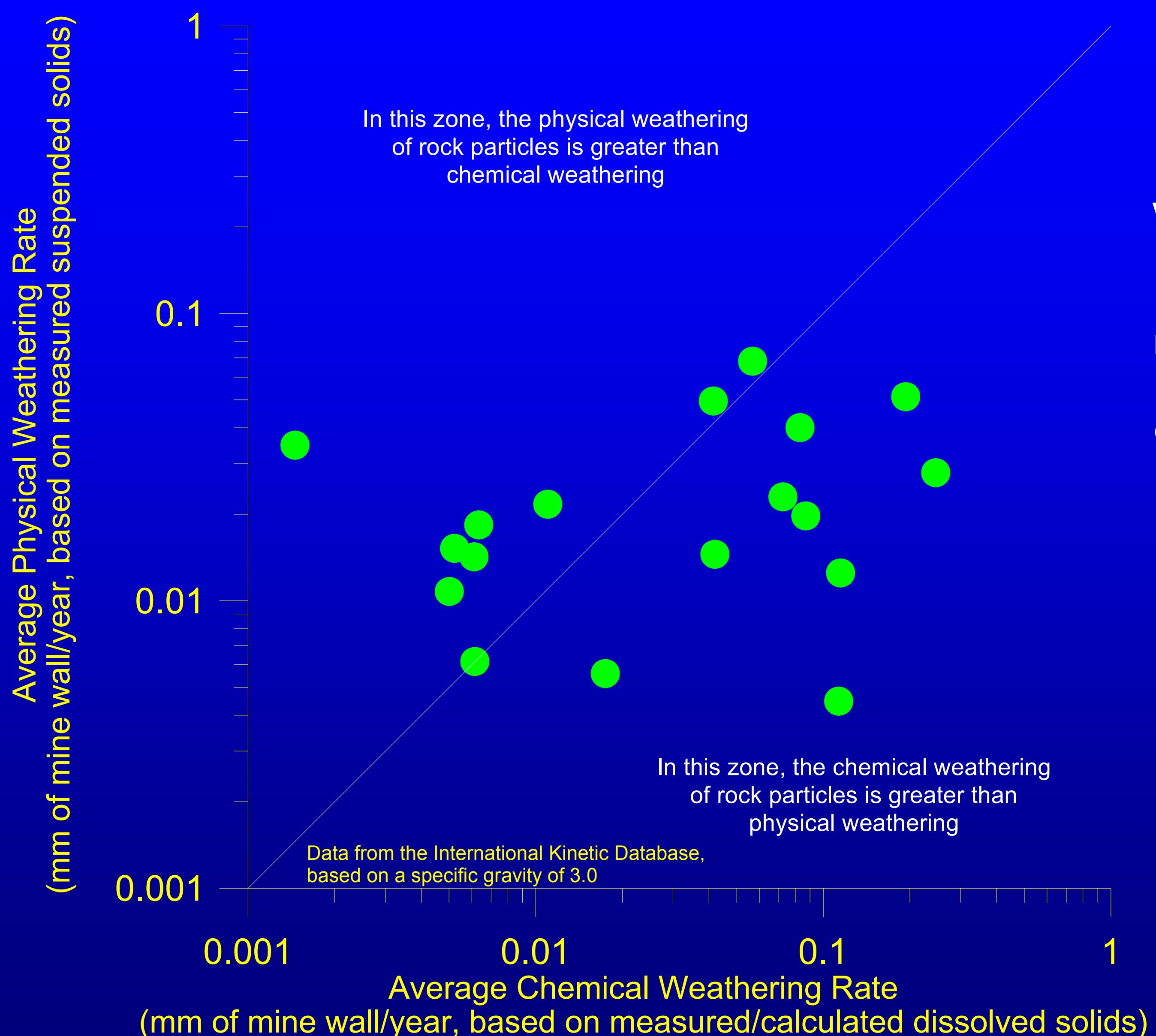


Time-series trends of total suspended solids at Minewall stations in an equatorial climate confirmed the continued physical weathering of the mine walls over a one year period.



This shows that the rates of chemical and physical weathering do not correlate with each other. One is greater than the other, depending on the sample.

It is typical to have at least a few hundred mg/m^2/wk of both physical and chemical weathering.



When the weathering rates are converted to mm of mine wall/year, average rates of both physical and chemical weathering are typically between 0.005 to 0.1 mm/year. This is not a major rate, but over 100 years of operation and closure becomes 0.5-10 mm.

For a large mine with 100×10^6 m^2 of reactive surface area, this is equivalent to ~1500-30,000 t/year of dissolved and suspended solids eroded from the walls.

Interesting Detail #2:

Can unit-area Minewall rates be accurately estimated from unit-weight rates in well-flushed Sobek humidity cells?

Detail #2: Unit-Area Rates from Unit-Weight Rates

- In the International Kinetic Database, there are several minesites that have rates for both humidity cells as unit-weight mg/kg/wk and for Minewall Stations as unit-area $mg/m^2/wk$.

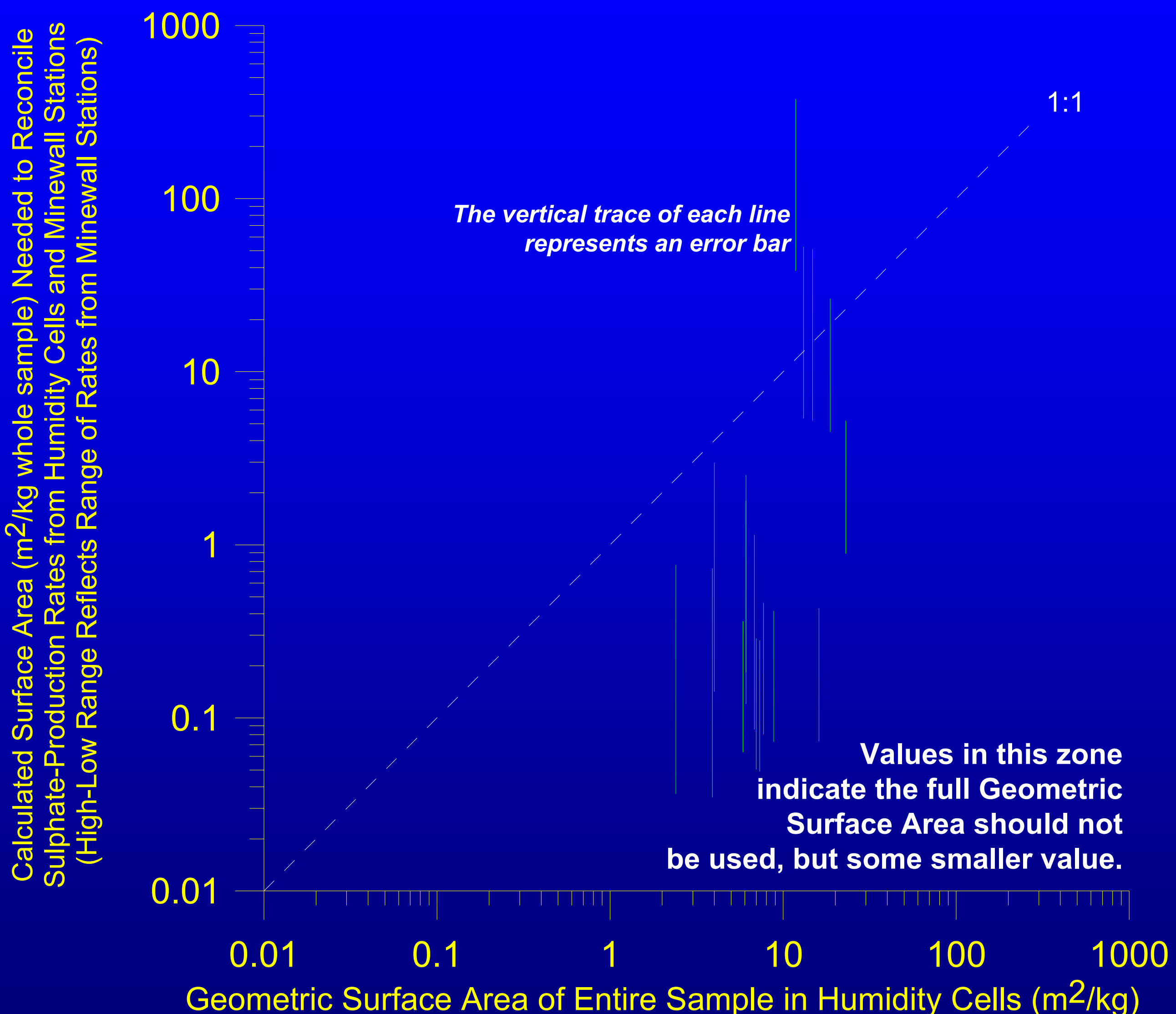
- Because Minewall Stations undergo thorough rinsing, comparisons were made only to cells that have undergone thorough rinsing (Sobek cells) or inundation for consistency.

Detail #2: Unit-Area Rates from Unit-Weight Rates

- Although identical samples were not tested in both the cells and the stations in the IKD, general comparisons using ranges (highs-lows) can be made to estimate the conversion factors needed to calculate unit-area station rates from unit-weight cell rates.

- Unit-Area Rate ($mg/m^2/wk$) =
  Unit-Weight Rate (mg/kg/wk) / "Surface Area" (m^2/kg)

- The "Geometric Surface Area" (GSA) is the grain-surface area of a humidity-cell sample (m^2/kg), based on a grain-size analysis with various sieves, specific gravity, and assumed grain shapes of cubes or spheres.

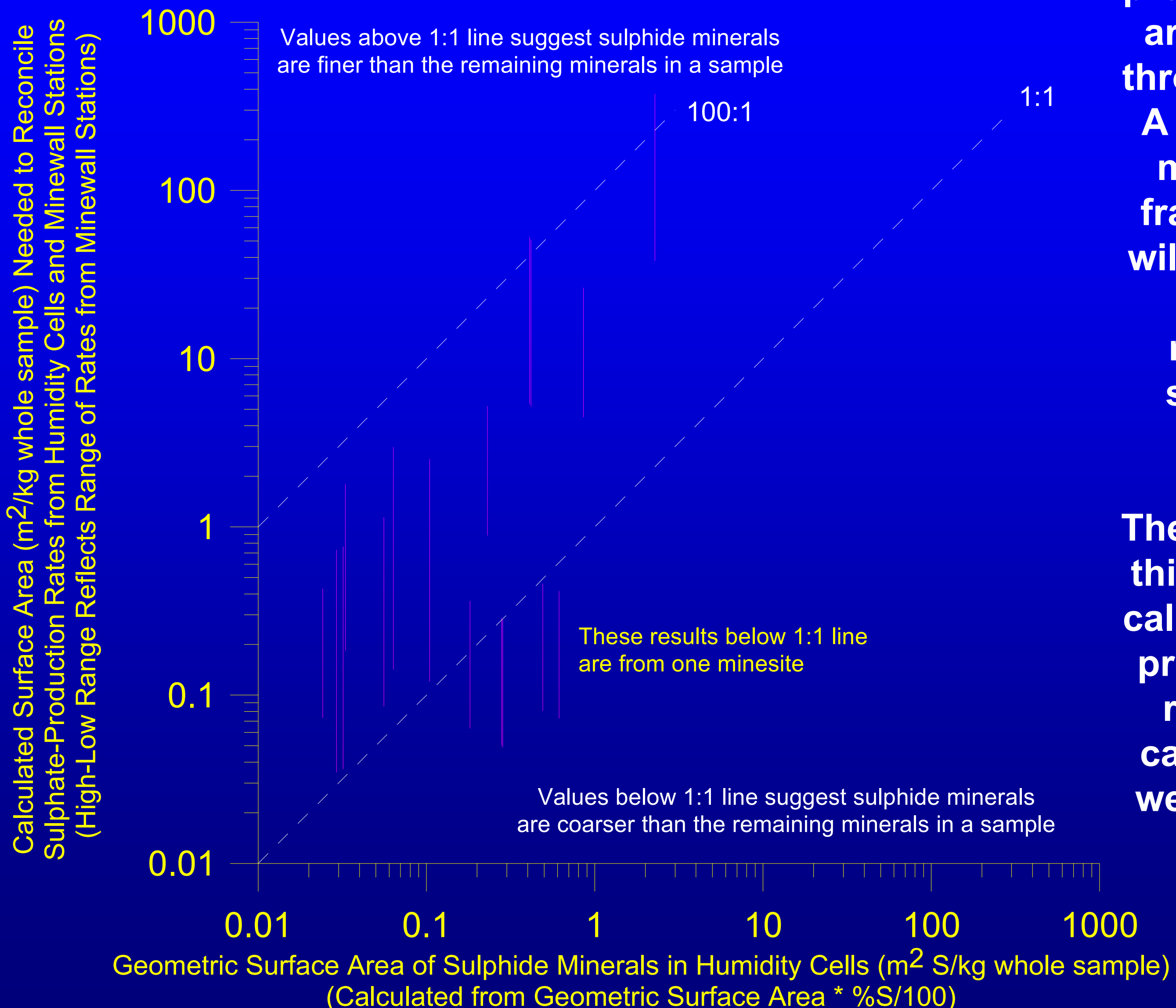


Data from the International Kinetic Database

For most comparisons of actual cells rates to actual Minewall rates, the Geometric Surface Area (GSA) was too high for accurate conversions. Instead, a smaller surface area was justified.

Therefore, calculated Minewall rates from cells rates usually should not use the GSA, but some smaller value. Due to the inverse relationship, a smaller surface area will lead to a higher calculated Minewall rate.

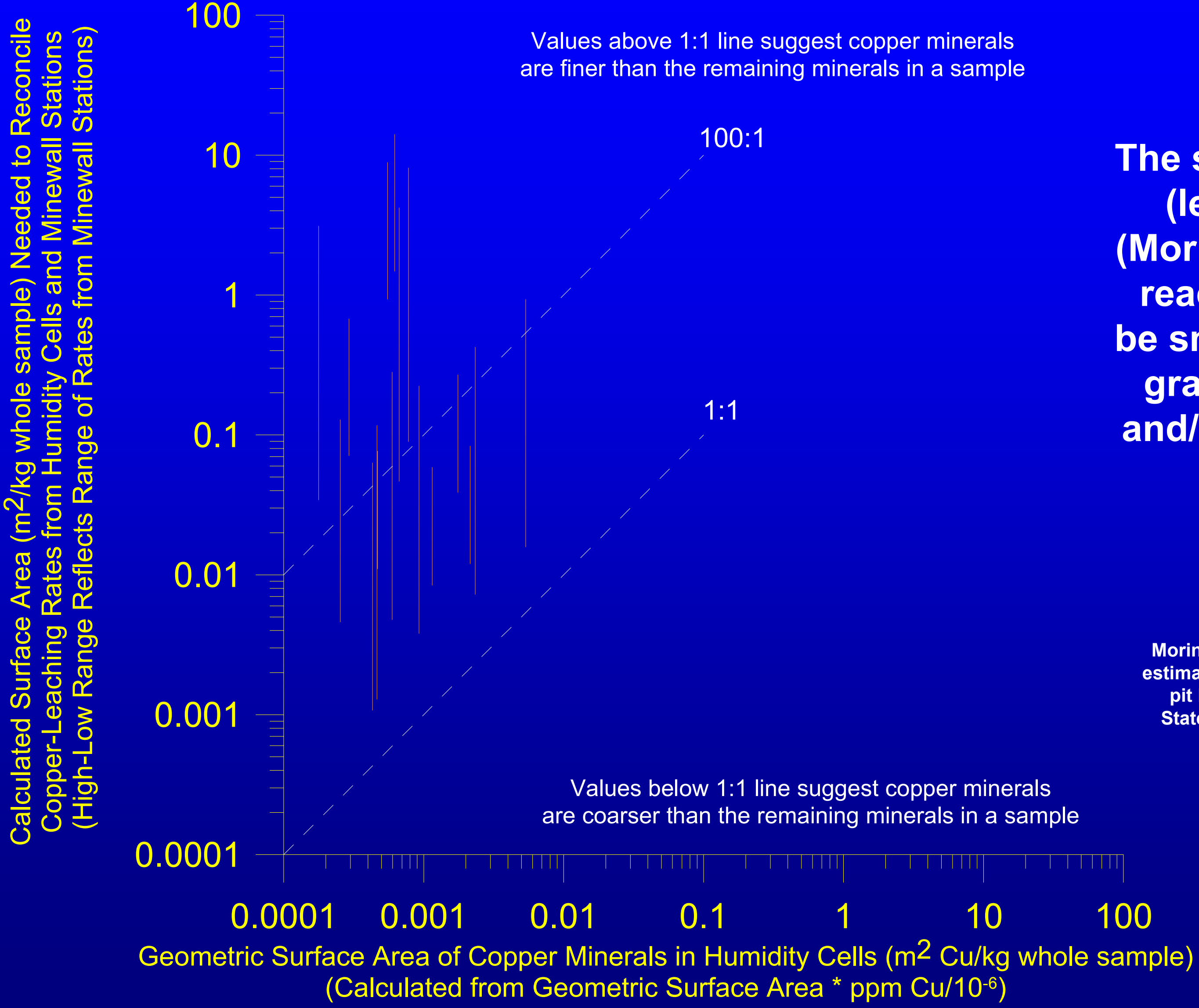
Why is a smaller value often needed?



Data from the International Kinetic Database

In the case of sulphate production, not all particles are contributing sulphate through sulphide oxidation. A simple adjustment is to multiply the GSA by the fraction of sulphide. This will be accurate if the grain size of the sulphide minerals are about the same as the rest of the sample.

The comparison shows that this is still not sufficient to calculate Minewall sulphate production rates from cell rates, because in many cases the sulphide grains were apparently finer than the overall sample.



The same applies to copper (left), zinc, and acidity (Morin and Hutt, 2005). The reactive grains appear to be smaller than the average grain size of the sample, and/or some other effect is operative.

Morin and Hutt. 2005. The Minewall Approach for estimating the geochemical effects of mine walls on pit lakes. Presented at Pit Lakes 2004; United States Environmental Protection Agency; Reno, Nevada; November 16-18, 2004.

Data from the International Kinetic Database

Detail #2: Unit-Area Rates from Unit-Weight Rates

Can unit-area Minewall rates be accurately estimated from unit-weight rates from well-flushed Sobek humidity cells?

Based on data from the International Kinetic Database (IKD):

- no, not accurately; Minewall stations are needed.

- rates can be roughly estimated from cells, but these rates could be an order of magnitude or more too high/low.

Conclusion

- The Minewall technique was developed for the MEND Program in 1990 and 1995, addressing both underground mines and open pits.

- Minewall uses the general mass-balance approach for all inputs and outputs of water and chemistry, plus the water level and chemistry of any accumulating mine water. Today, much of this can be done in a spreadsheet, but 10-15 years ago this required custom programming.

- Minewater chemistry can be adjusted through mineral precipitation-dissolution, etc.

Conclusion

- The geochemical contribution from mine walls was based on the decades-old unit-area approach, modified as needed by any fine-grained material in the mine.
- Minewall stations are used to obtain unit-area rates.
- Rock surfaces are not stable, persistent surfaces, but experience ongoing physical and chemical weathering.
- Unit-area rates cannot be easily obtain from unit-weight rates, like those obtained from humidity cells.

THE END

This presentation can be downloaded free-of-charge at:
www.mdag.com

A spreadsheet (Grain 3.0) for calculating Geometric Surface Areas from grain-size analyses can also be downloaded free-of-charge.