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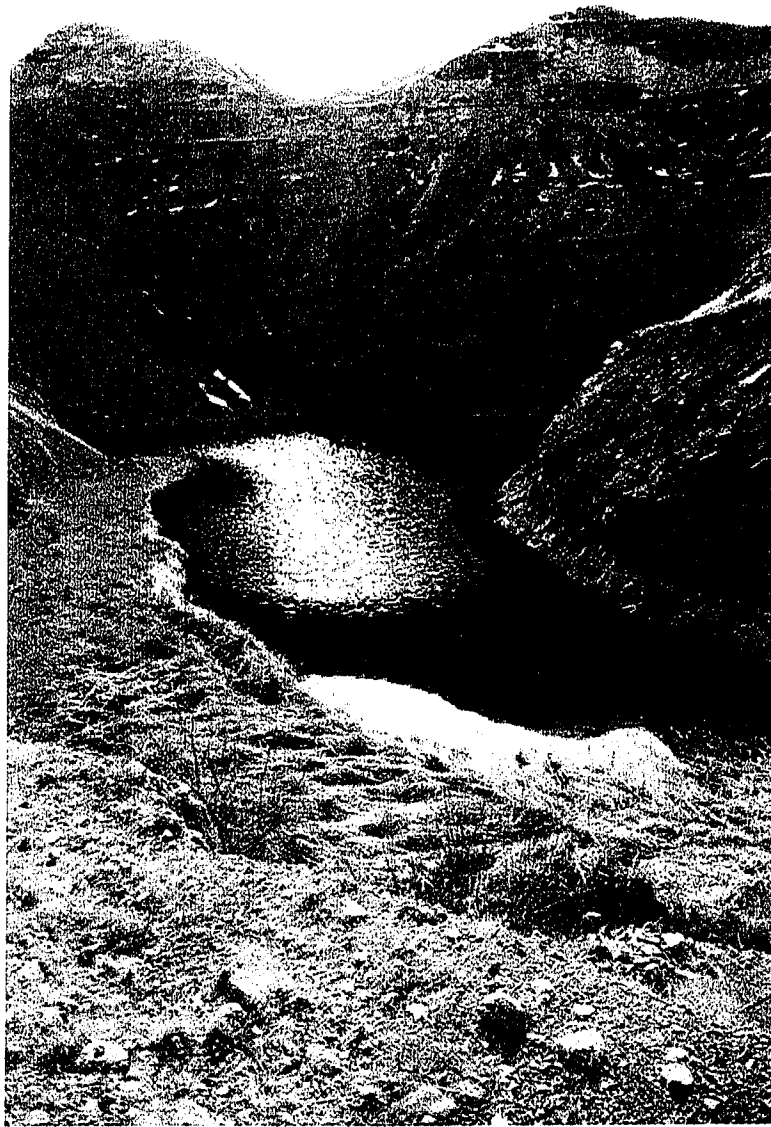
PREDICTION OF PIT LAKE DRAINAGE CHEMISTRY

Andy Davis
Geomega

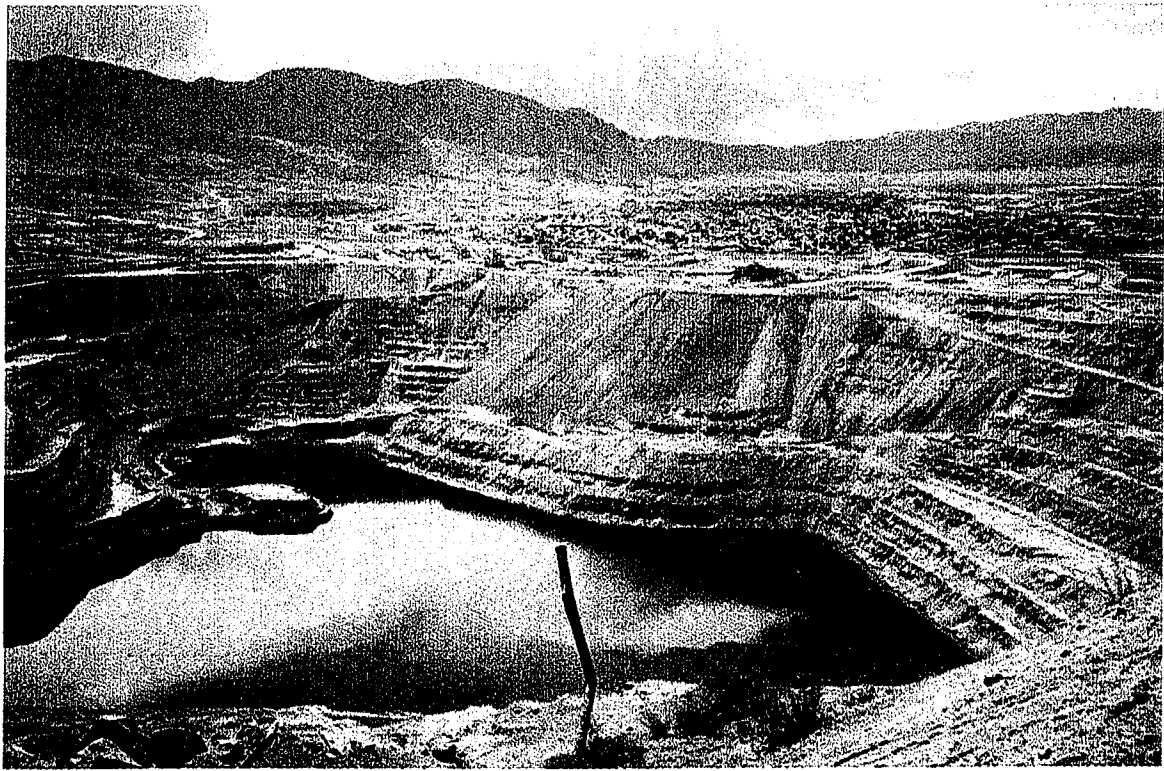
A Method to Predict Evolving Post-Closure Pit Lake Chemistry

by:

Andy Davis, Ph.D. Geomega
George Fennemore, Ph.D., Geomega







The Ying and the Yang of Pit Lake Chemistry (mg/L)

	Berkeley Pit	Cortez Pit
pH	2.8	8.1
As	0.05	0.038
Fe	386	0.134
Mn	95	0.002
Zn	280	0.002
Cl	9	24
SO ₄	5740	90

Flow Chart Describing Progress and Integration of Pit Lake Chemical Prediction

Objective

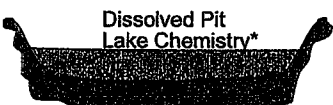
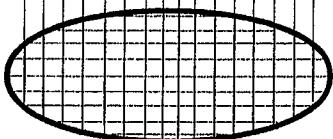
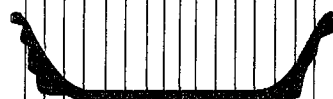
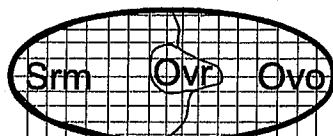
Ultimate Pit Surface
Geologic Block
Model

Ultimate Pit Surface
Oxidation Potential

Weathering Rind
Thickness

Post Closure
Groundwater
Discharge to Pit

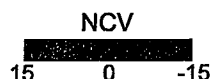
Geochemical
Constraints



Limnology
Chemogenesis*
Evapoconcentration*
Attenuation Region*

Tool

Pipeline/South
Pipeline Geology



Chemical Release
Functions

Regional
Groundwater Model
Elemental Discharge

Solute Mass Discharge
Pit Lake Volume

PHREEQC

CE-QUAL-W2

*Requires Field Specific Data

Leaching Tests

Methods

Meteoric Water Mobility Tests
Column Tests
Humidity Cell Tests
Field Oxidation and Leaching Tests

Issues

Acid Generating/Neutralizing Potential
Reactive Surface Area (particle size)

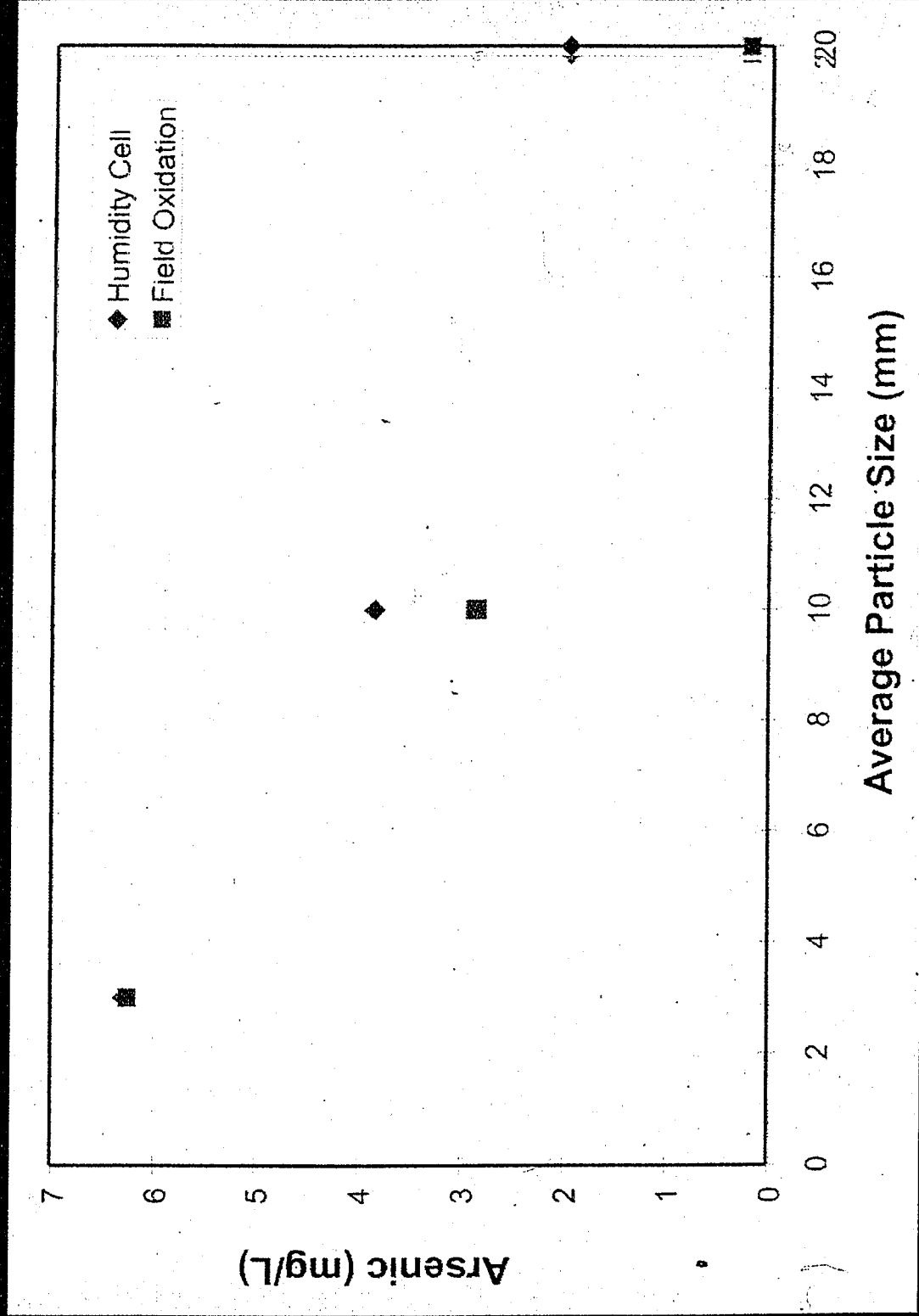


	Precipitation
a	2-4 mm
b	4-16 mm
c	16-64 mm
d	<2 mm
f	2-4 mm
g	4-16 mm
h	16-64 mm

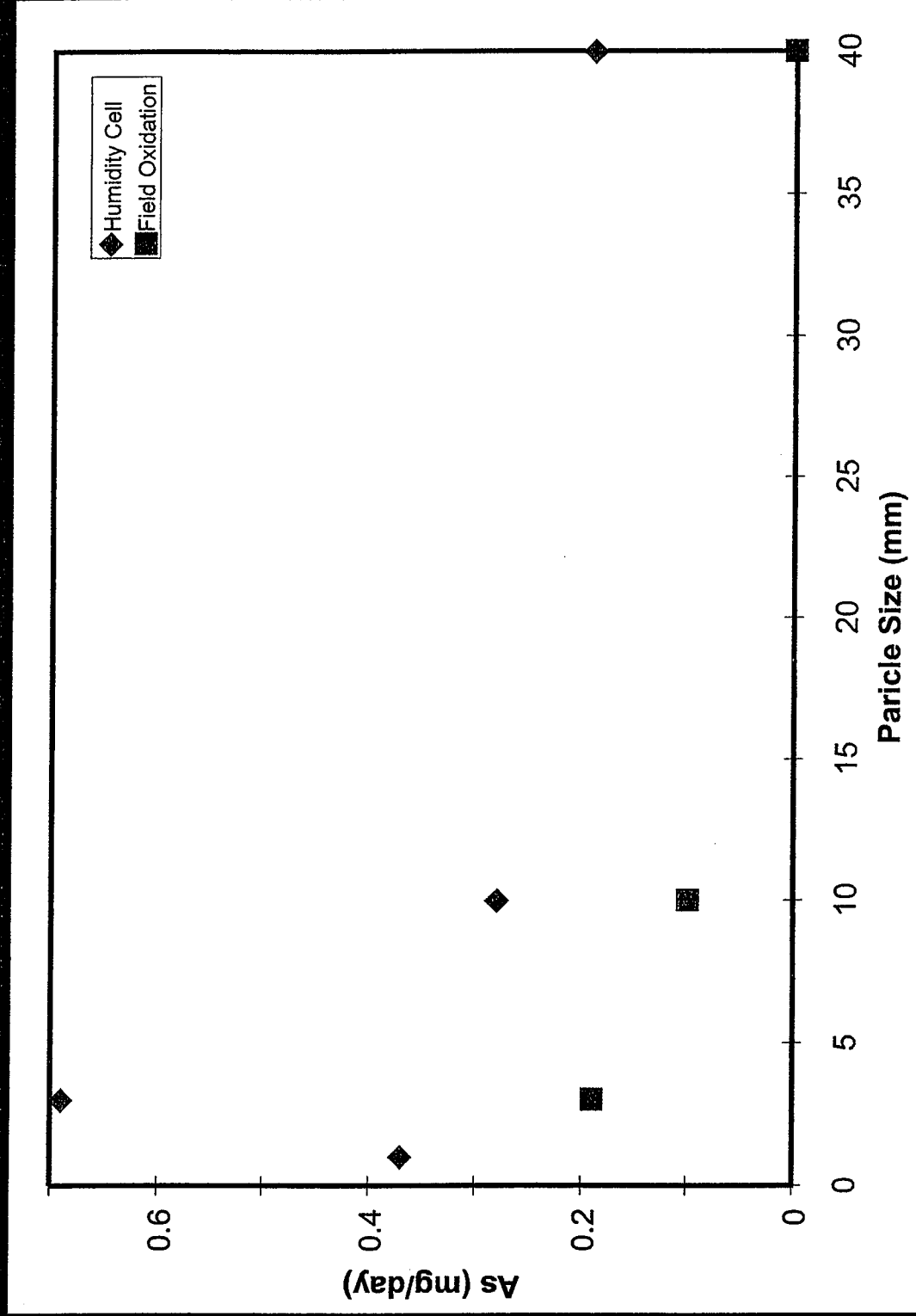
Humidity Cell



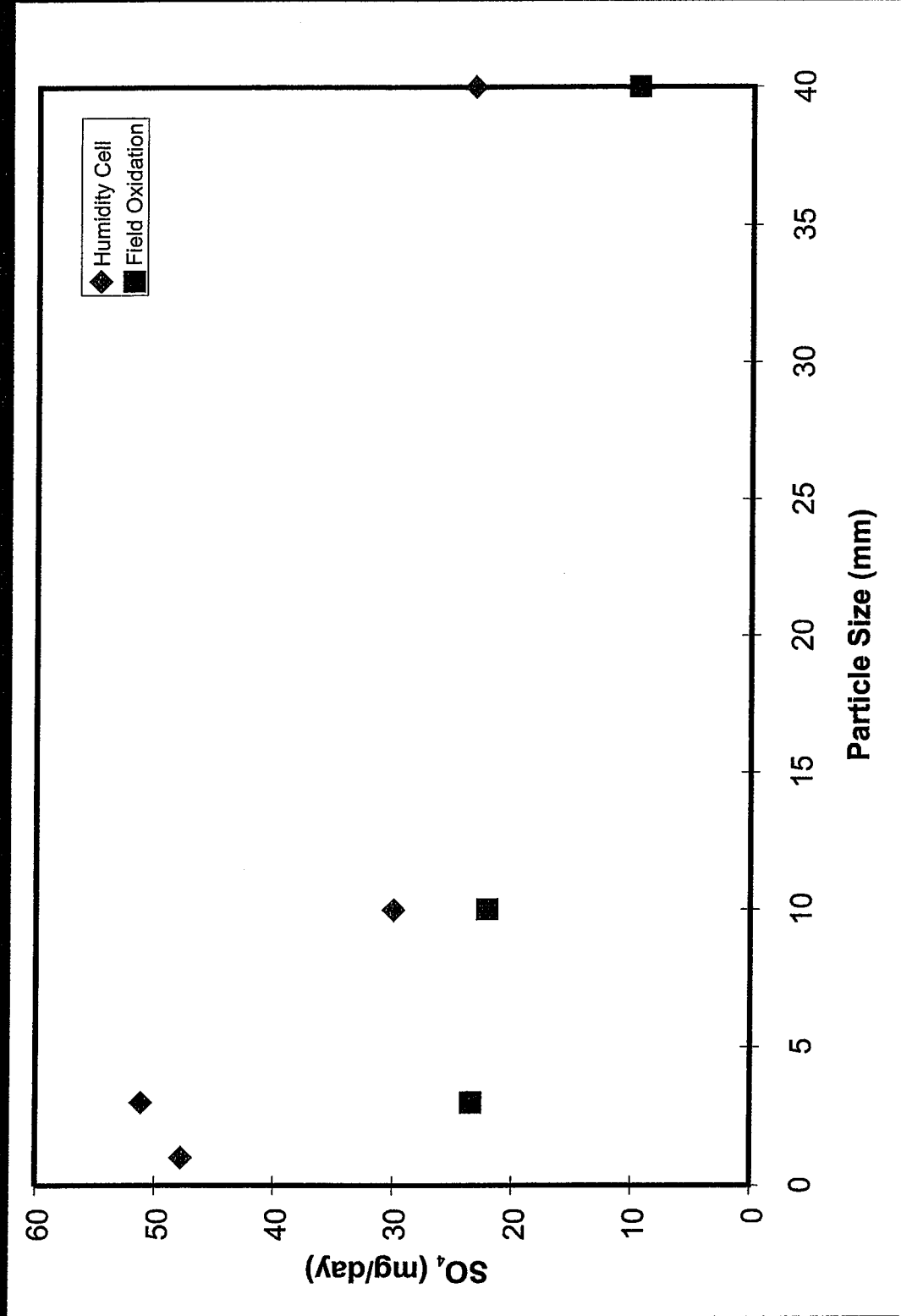
Average SSR3 Arsenic Concentrations



Arsenic in Field Oxidation and Humidity Cell Leachates



Sulfate in Field Oxidation and Humidity Cell Leachates



Pyrite Oxidation Model

Based on the Davis-Ritchie Approach

Modifications

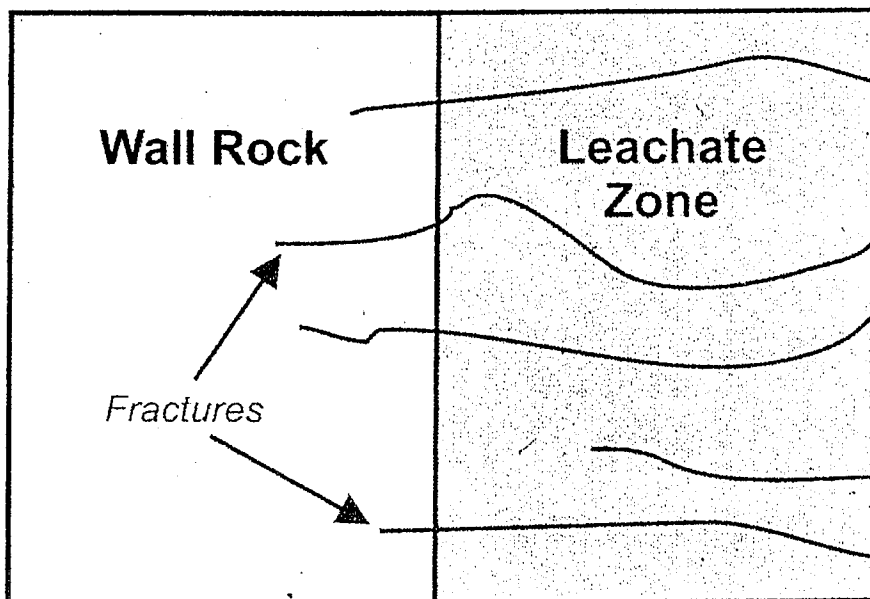
Wall Rock Geometry – Fractures versus Porous Media
Water Content Oxidation Rate Limitation

Other Features

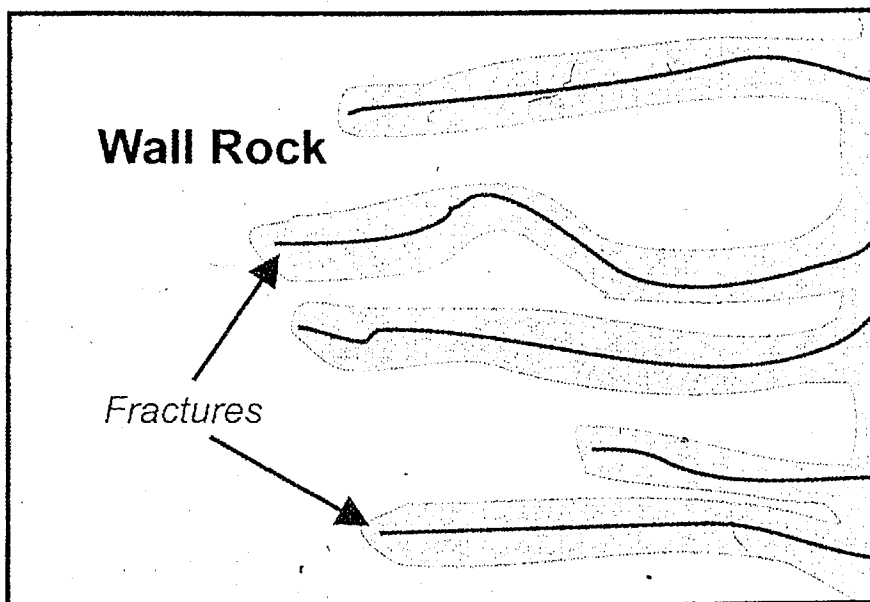
Variable Air-Filled Porosity
Variable Particle Size

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Bulk vs. Fracture Based Pyrite Oxidation



Planar Approach



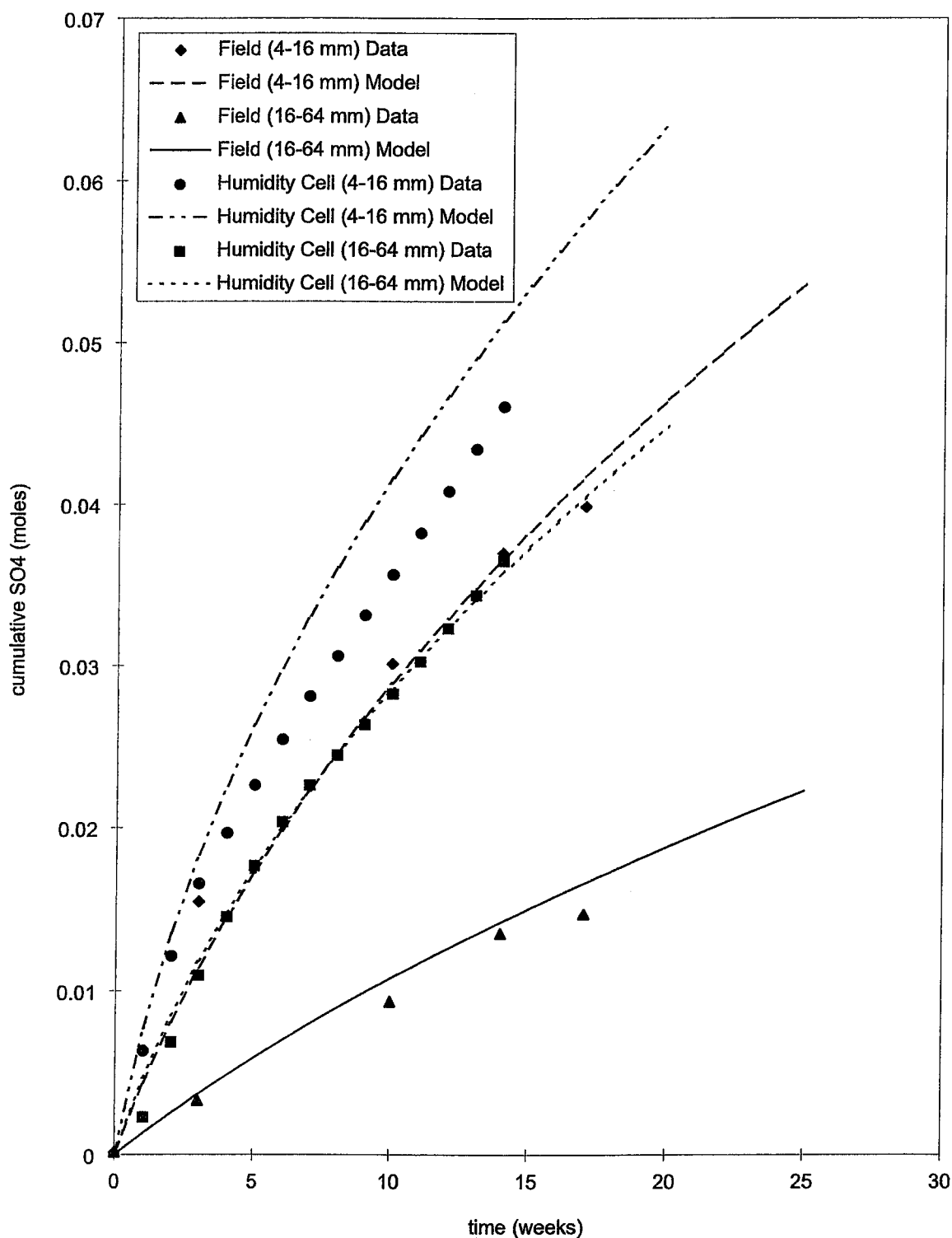
Layered Approach

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Photogrammetric Analysis of Macro-Fracture Density in the SOAP-GQ Pit Wall Rock

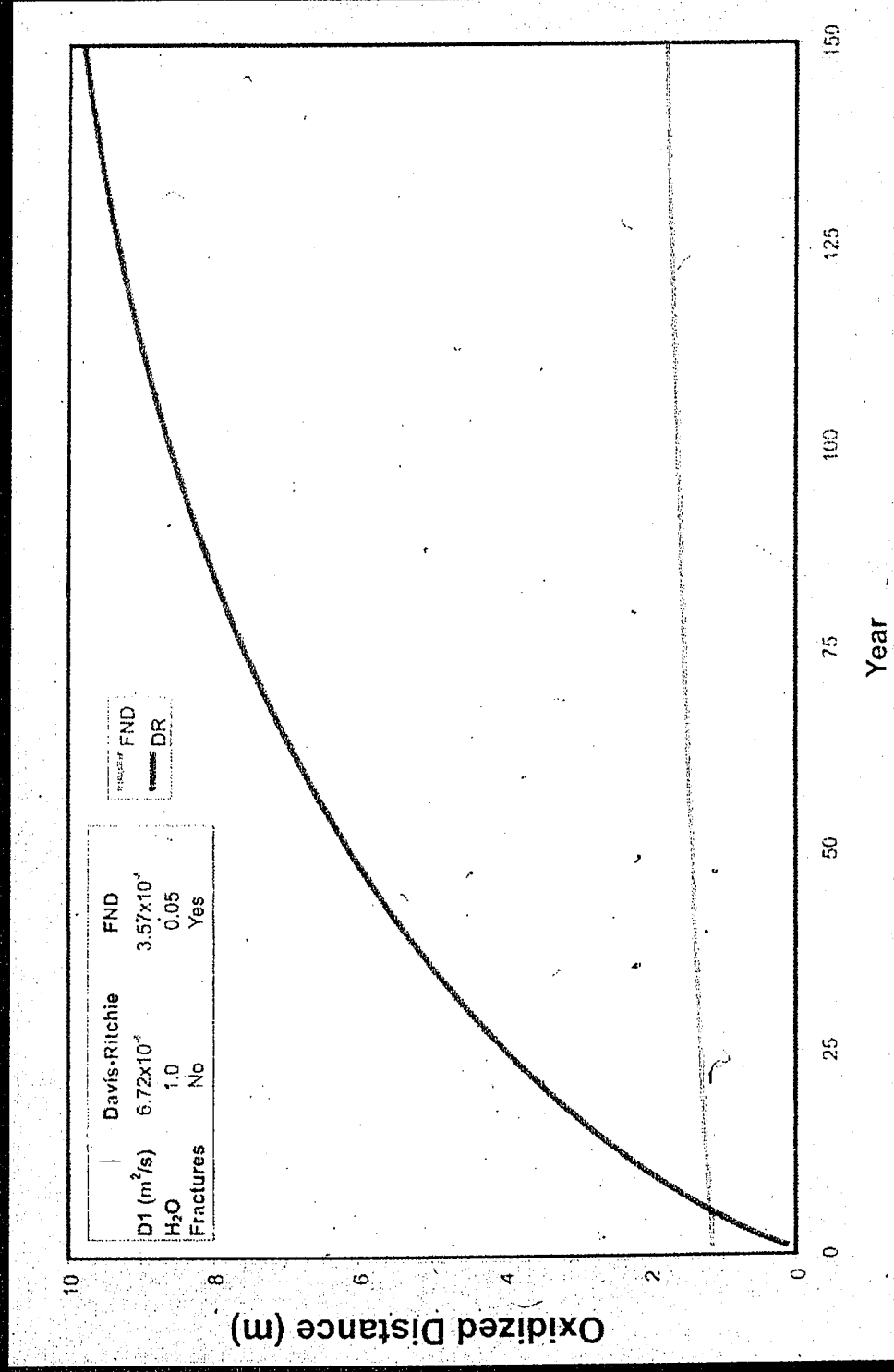


Observed Rate Limitation in Pyride Oxidation



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Comparison Between Davis-Ritchie and FND Models for SSR2 Rock (NCV<-1)



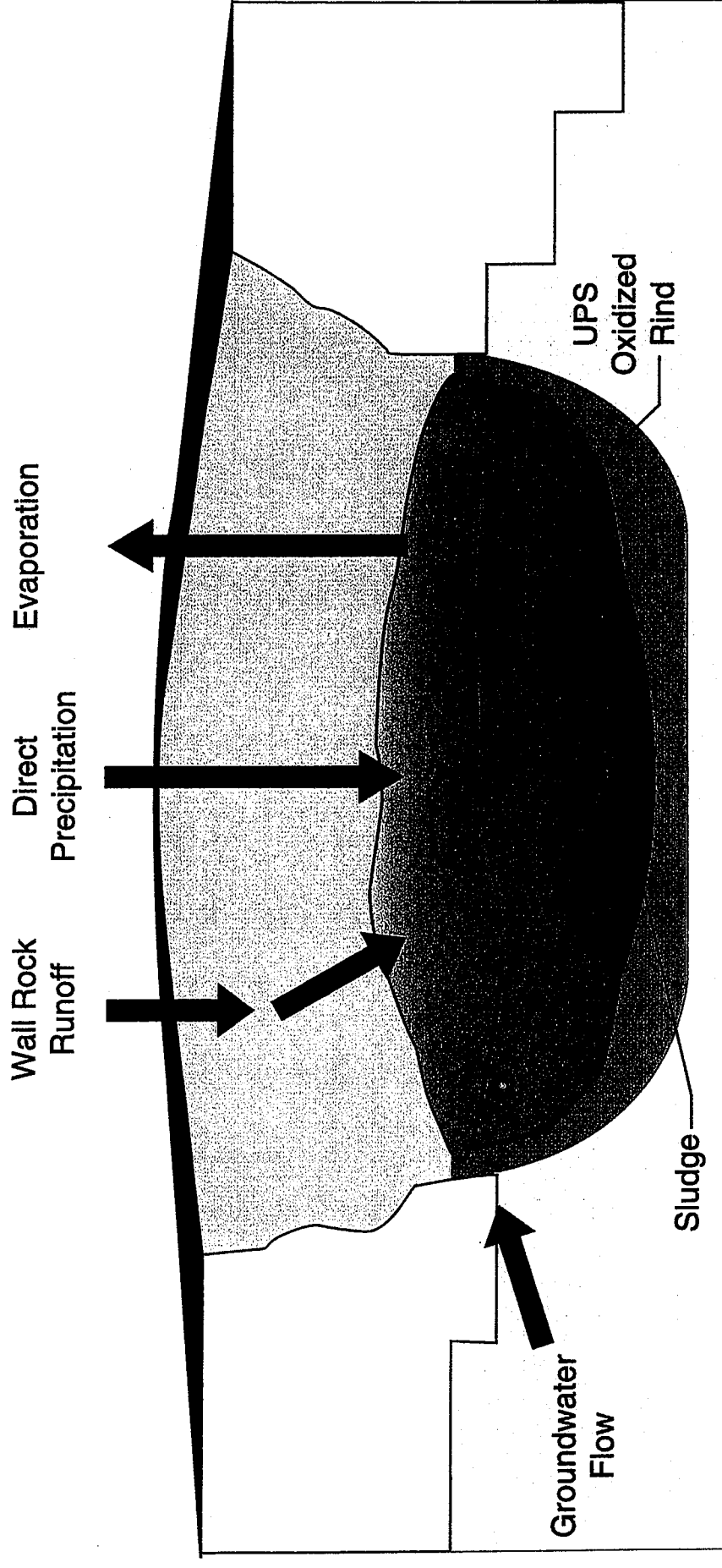
Bulk Chemistry

Total mass of solutes contributed by:

Wall Rock Leaching
Groundwater Inflow
Surface Runoff
Precipitation
Groundwater Outflow

[Illegible text in right margin]

Schematic of Hydrologic Cycle for a Refilling Pit



Dissolved Chemistry

1. Mix various solutions
2. Evapoconcentration
3. Solid and Gas Phase Equilibrium
4. Sorption to AFH
5. Charge Balancing
6. Analog Test

Equilibrium Phases

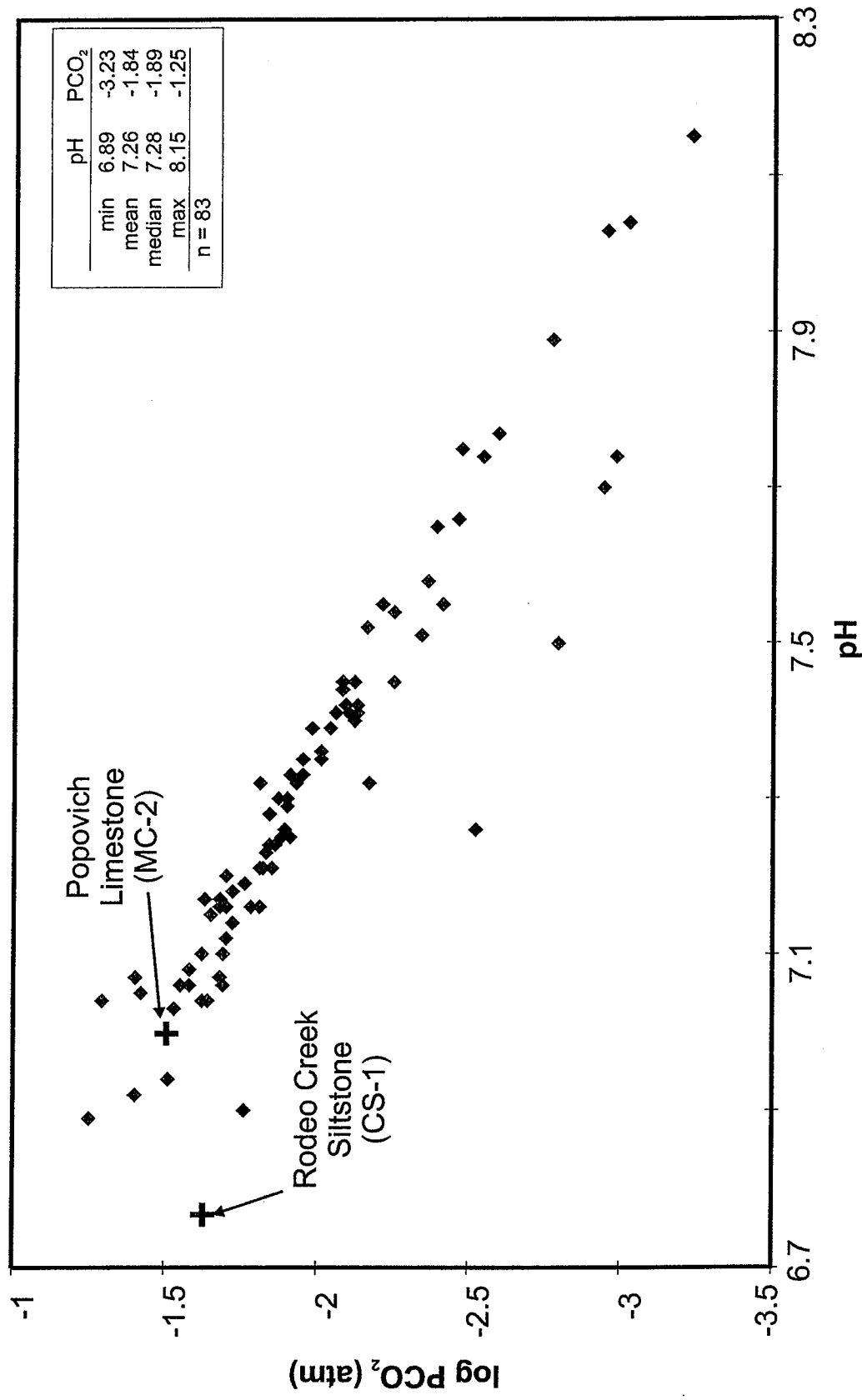
Gases

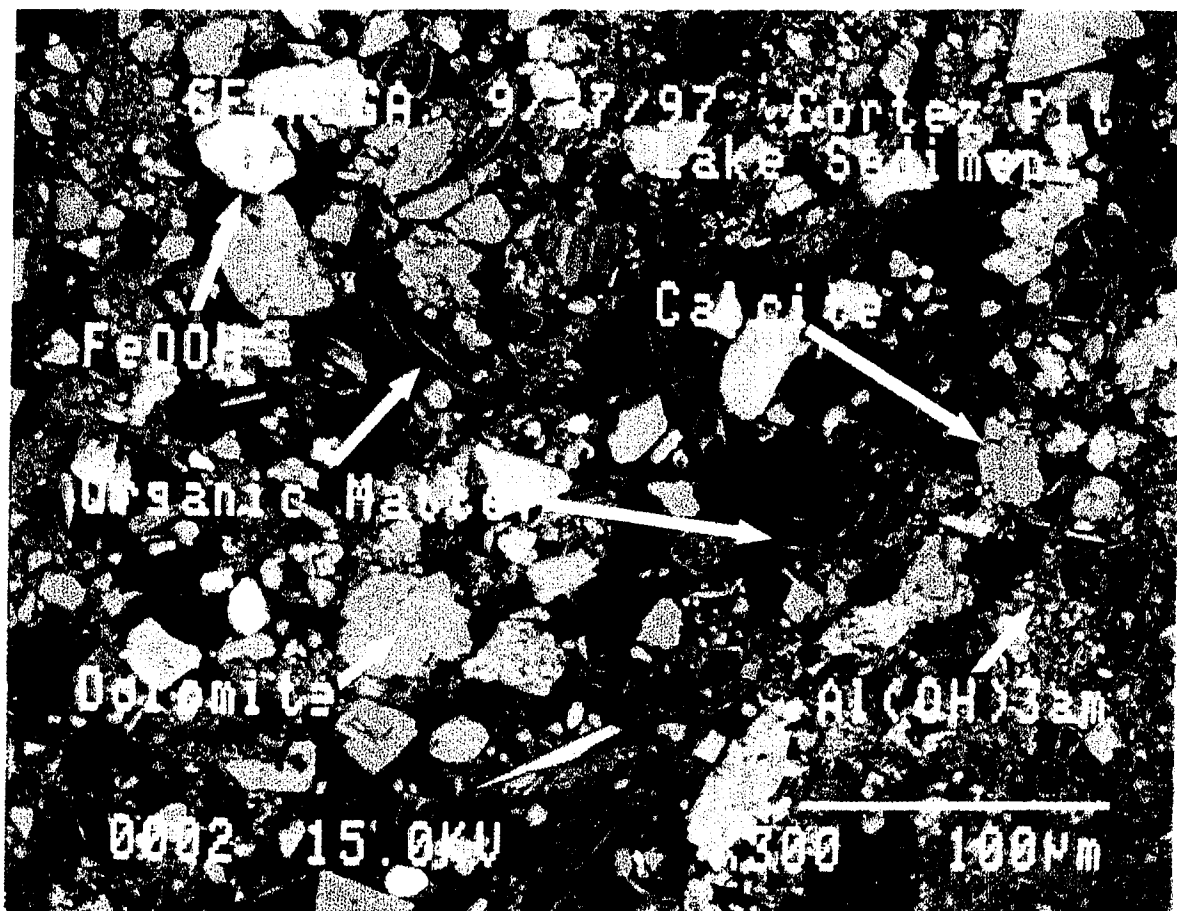
Carbon Dioxide
Oxygen

Solids

Amorphous Ferric Hydroxide
Calcite
Gibbsite
Barite

PCO₂ as a Function of pH in Carbonate Aquifers







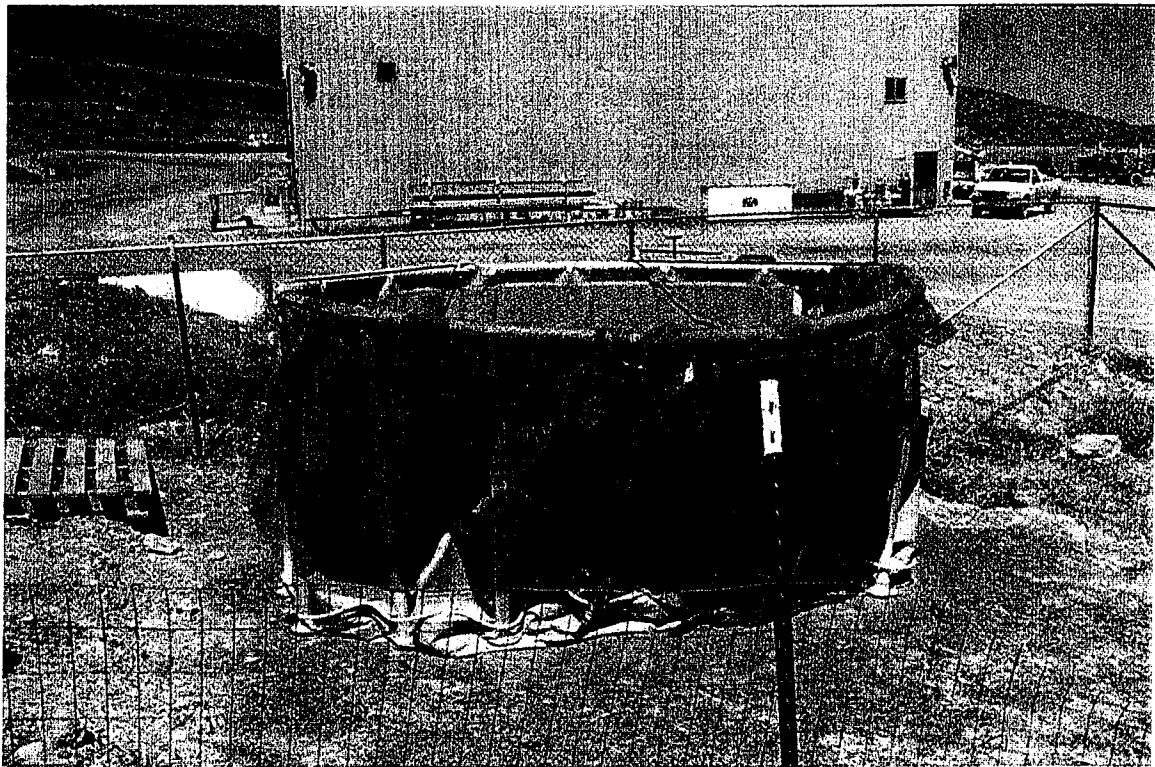


Evapoconcentration

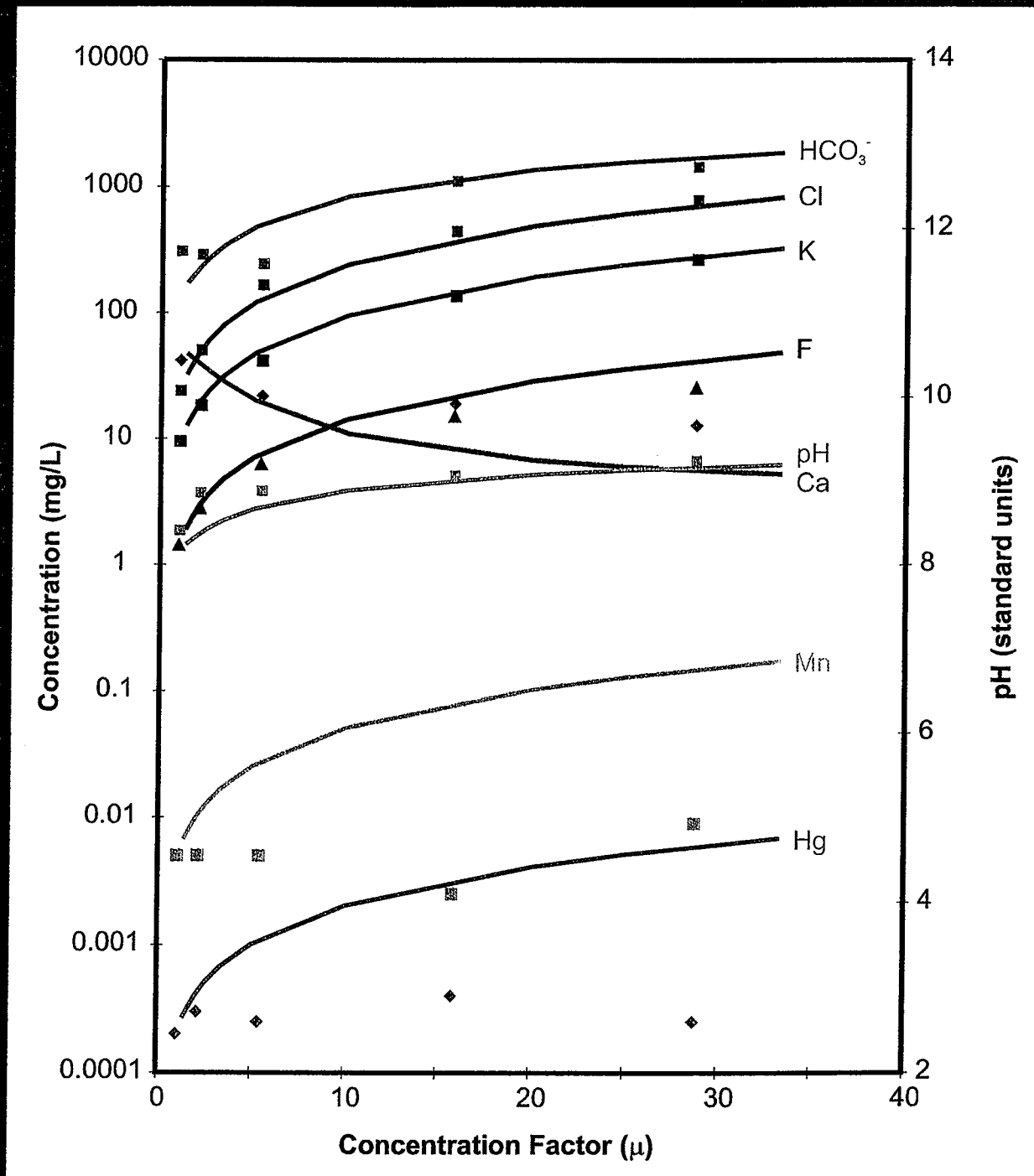
Theory of Geochemical Divides

Field Tests

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Pipeline/South Pipeline Evapoconcentration Experiment: Predicted (—) and Experimental (■) Data



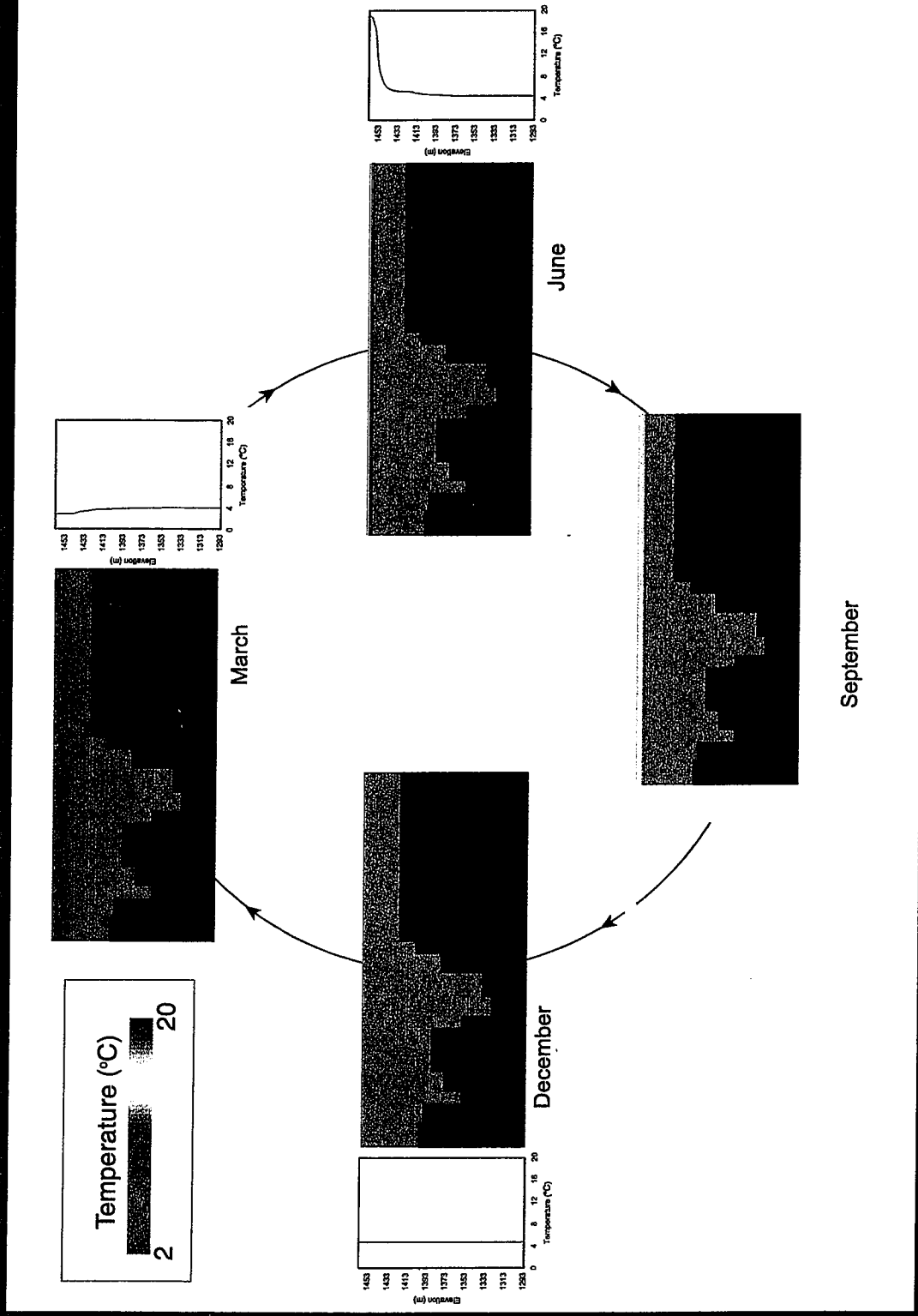
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Hydrodynamic Model

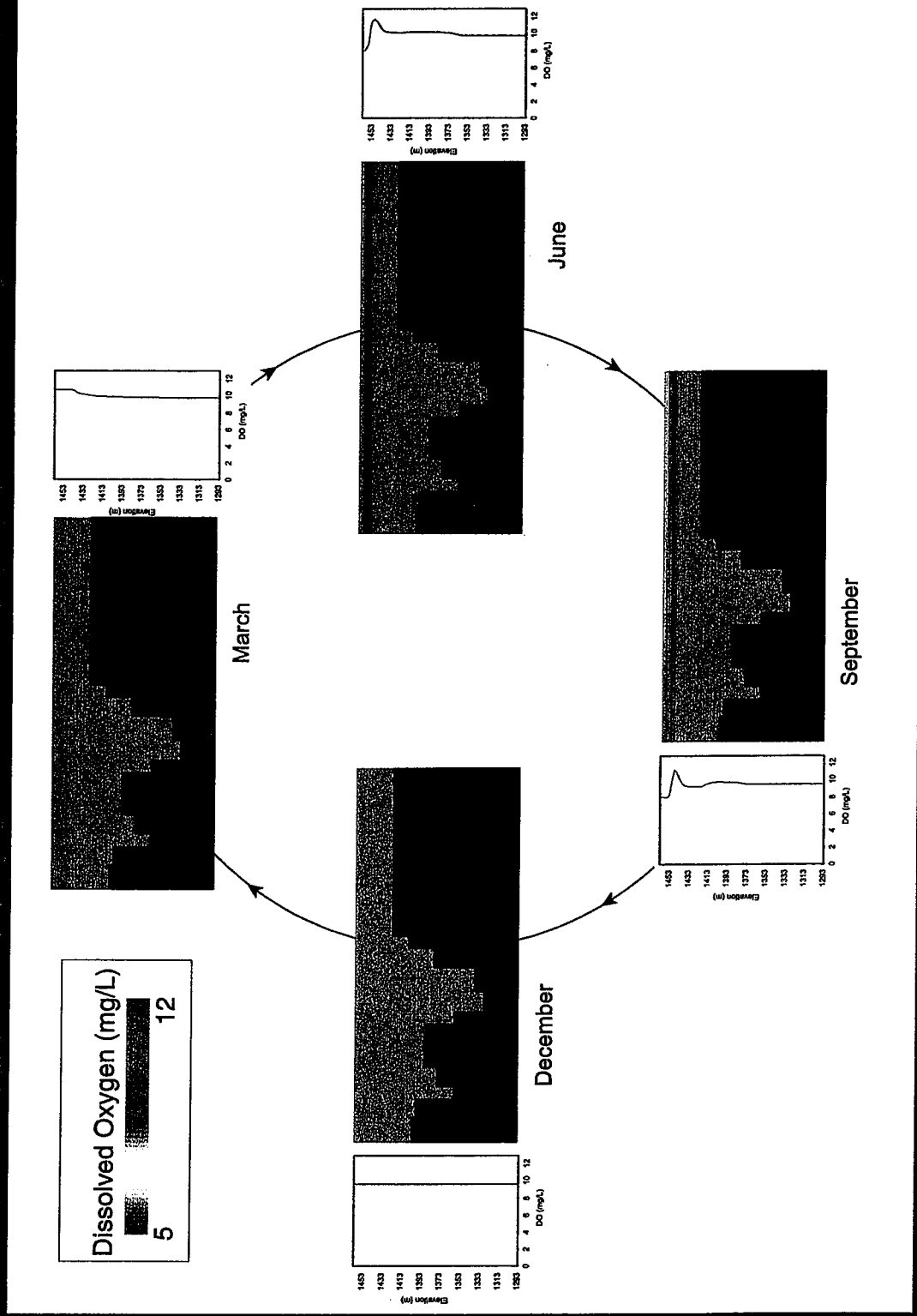
Does the pit lake mix and turn over?

Does the pit lake become anoxic?

Temperature Profiles for the Dual Pit Lakes with Waste Rock Scenario



Dissolved Oxygen Profiles for the Dual Pit Lakes with Waste Rock Scenario



Comparison of Predicted Pit Lake Water Quality to an Analog Pit Lake

Analyte	Cortez Pit Lake (20 years after refilling)	Predicted South Pipeline Pit Lake (20 years after refilling)
pH	8.07	8.19
alkalinity	282	265
arsenic	0.038	0.020
calcium	45	66
chloride	24	85
fluoride	2.4	2.9
iron	<0.01	0.0004
sodium	69	123
sulfate	90	219
TDS	432	810

Conclusions

This methodology for predicting pit lake water quality is proposed for fulfillment of the technical requirements for an Environmental Impact Statement, or as part of permitted facility closure.

- Improved definition of constraints on pyrite oxidation in arid environments
- More accurate representation of leaching characteristics of wall rock

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Comments

Issue	Remedy
Determination of background water quality	monitoring well samples, appropriate detection limits
Wall rock leachate quality	laboratory/field testing, leaching of representative samples
Oxidation modeling	results of the leaching tests, characterization of rock fractures and porosity
Bulk chemistry	water balance, groundwater flow model
Dissolved chemistry	identification of equilibrium phases, evapoconcentration tests, analog tests
Hydrodynamic modeling	comparison to existing lakes
Other influences	microbial activity

