IOM3/AusIMMM Webinar Series:

An Overview of Electric Pulse Treatment of Ores & Applications in Mineral Processing

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AusIMM/IOM^3 February 2022

Lightning Machines
Mineral Processing Research

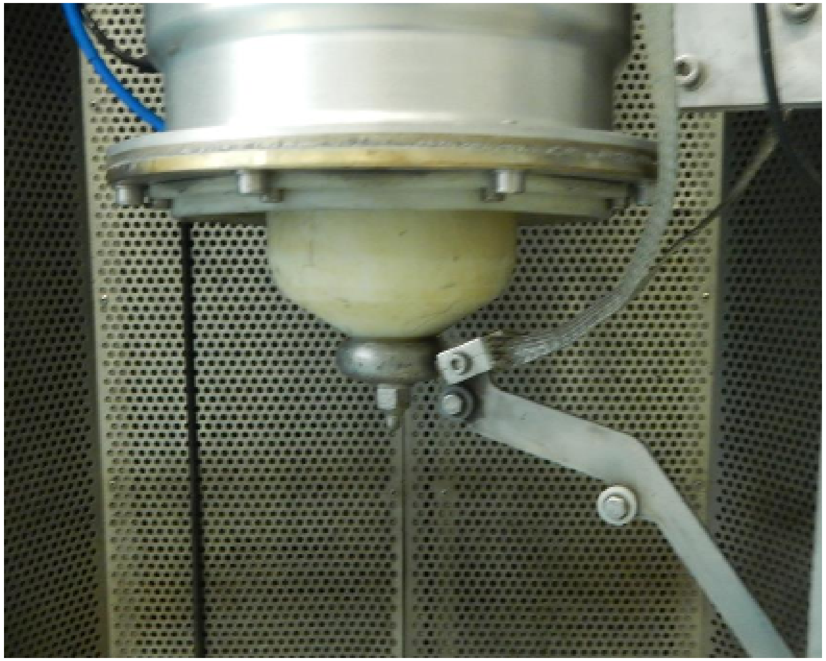
Contents

Introduction to Electric Pulse Fragmentation: theory and practical applications

Contents

High Voltage Fragmentation

SelFrag Lab System



Research Users

Lab Users

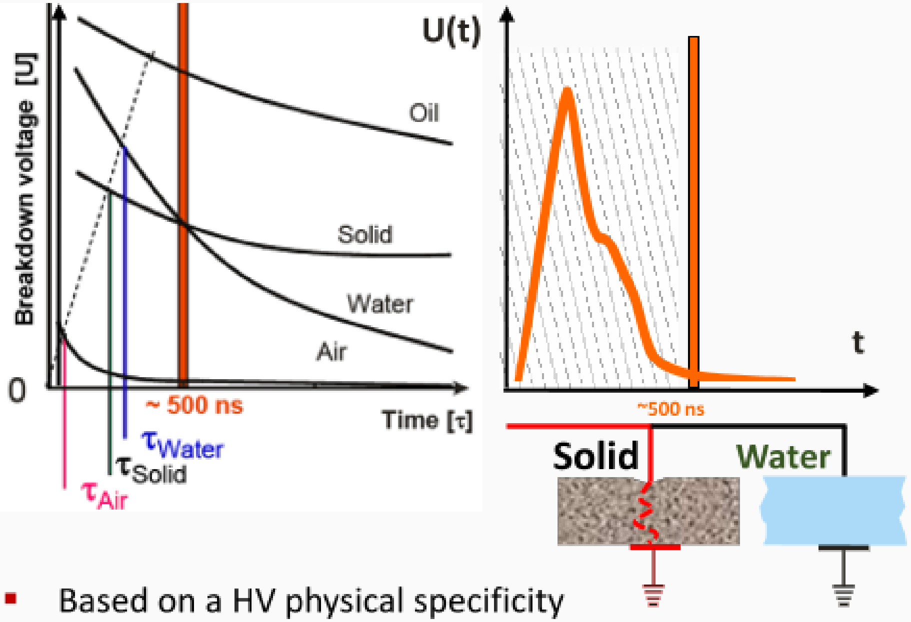
	Organisation	Country	Application
1	University of Bern	Switzerland	Geoscience & Recycling
2	GTK	Finland	Mining & Geoscience
3	Goethe Universität Frankfurt	Germany	Geoscience
4	TU Freiberg	Germany	Geoscience & Mining
5	ETH Zürich	Switzerland	Geoscience
6	SELFRAG	Switzerland	-
7	Fraunhofer Institut	Germany	Recycling
8	FH Pforzheim	Germany	Recycling
9	Leoben	Austria	Mining
10	FHNW	Switzerland	Recycling
11	University of Liège	Belgium	Recycling
12	BRGM	France	Recycling
13	NTNU	Norway	Mining, Geoscience
14	Université de Lorraine - Nancy	France	Mineral Processing
15	BGS	UK	Geoscience
16	SUERC	UK	Geoscience

	Organisation	Country	Application
1	JKMRC	Australia	Mining
2	Macquarie University	Australia	Geoscience
3	Curtin University	Australia	Geoscience
4	University of New South Wales	Australia	Recycling

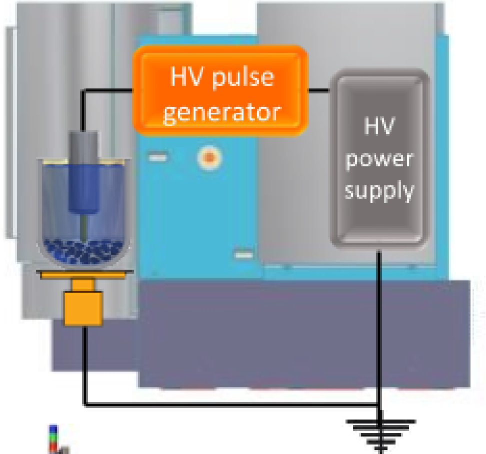
High Voltage Fragmentation

How does HV fragmentation work?

HV pulse power technology



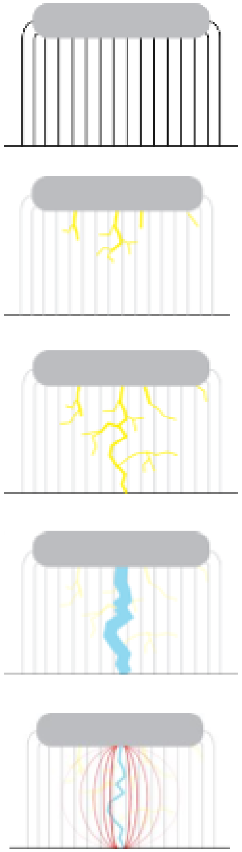
- Based on a HV physical specificity
- At short pulse rise time solid more conductive than water
- Discharge occurs through solid, causing strong internal shockwaves resulting in selective breakage



Process
vessel with
electrode
in water

High Voltage Fragmentation

Discharge/Fragmentation Steps:
Shockwave is the main cause of fragmentation

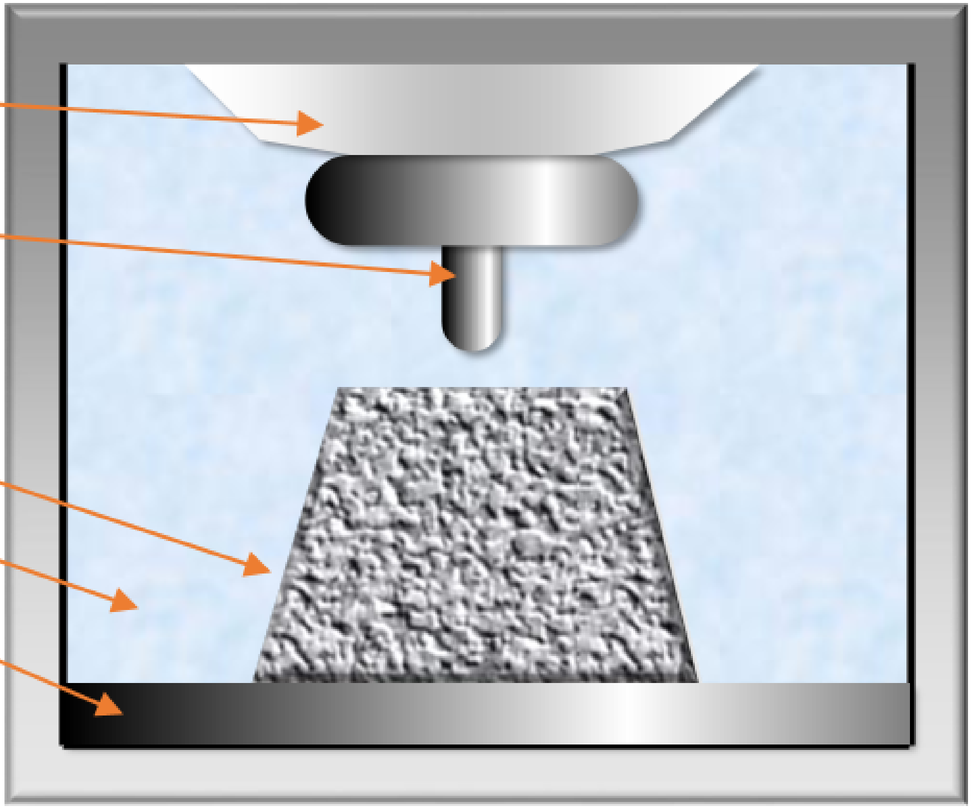


Discharge process	Fragmentation process
Formation of the electrical field	
Plasma streamer creation and growth	Streamers get attracted to areas of strong field distortion
Plasma streamer(s) bridge the gap between electrodes and create a discharge	
Plasma channel expansion due to Ohmic heating	Localised crushing due to high pressures (GPa) range
Plasma channel collapse	Shockwave emission causes tensile fracturing enhanced by plasma percolation into fractures

High Voltage Fragmentation

High Voltage Fragmentation

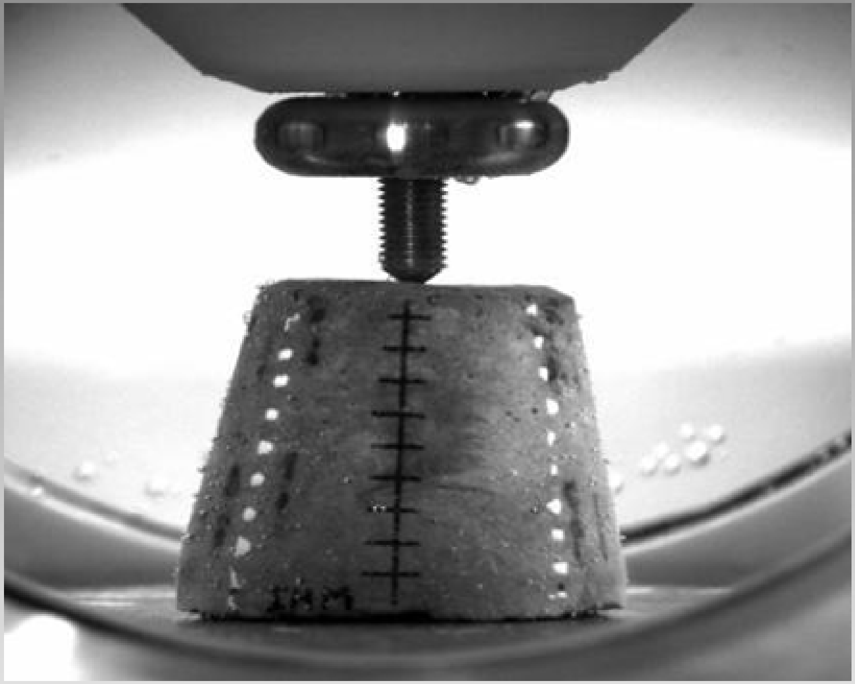
High Voltage Fragmentation



- Isolator
- HV-Electrode
- Sample
- Process water
- Ground Electrode

High Voltage Fragmentation

- Isolator
- HV-Electrode
- Sample
- Process water
- Ground Electrode



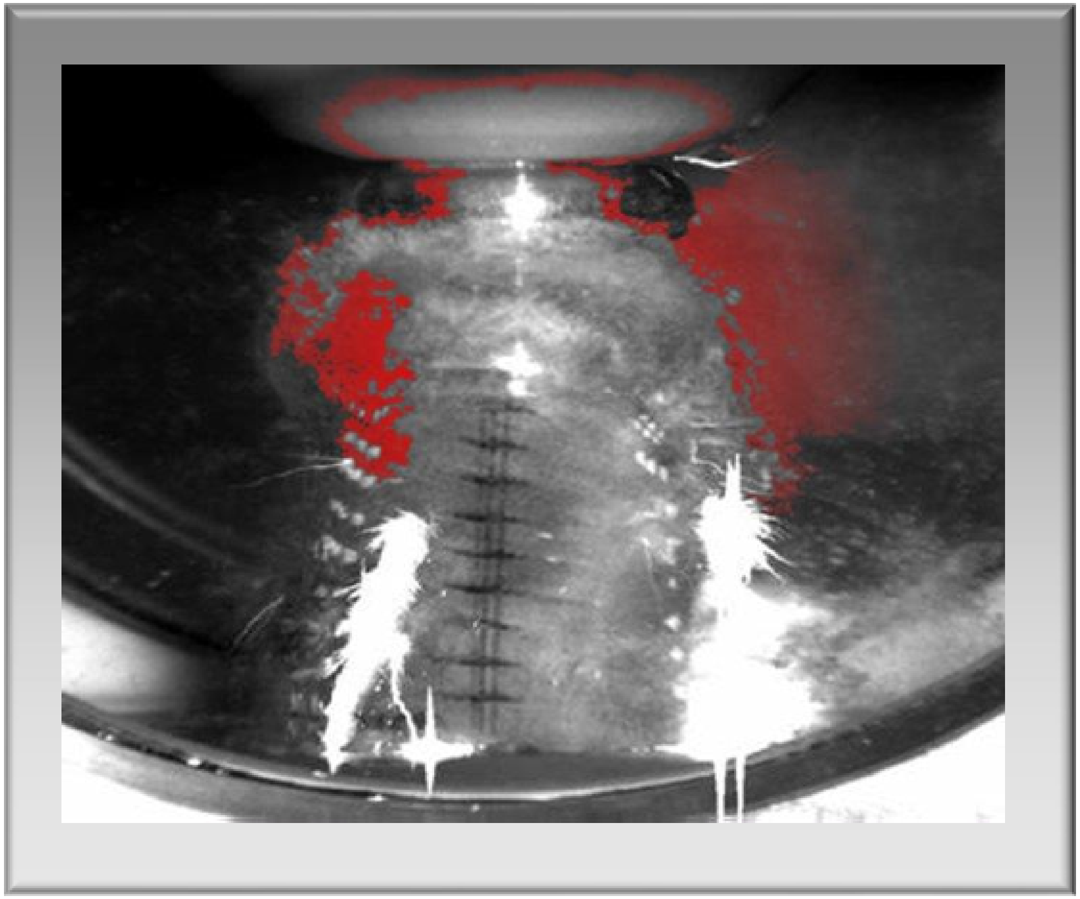
High Voltage Fragmentation

What you can see:

→Plasma channel inside sample

→Plasma expansion "blasts" sample

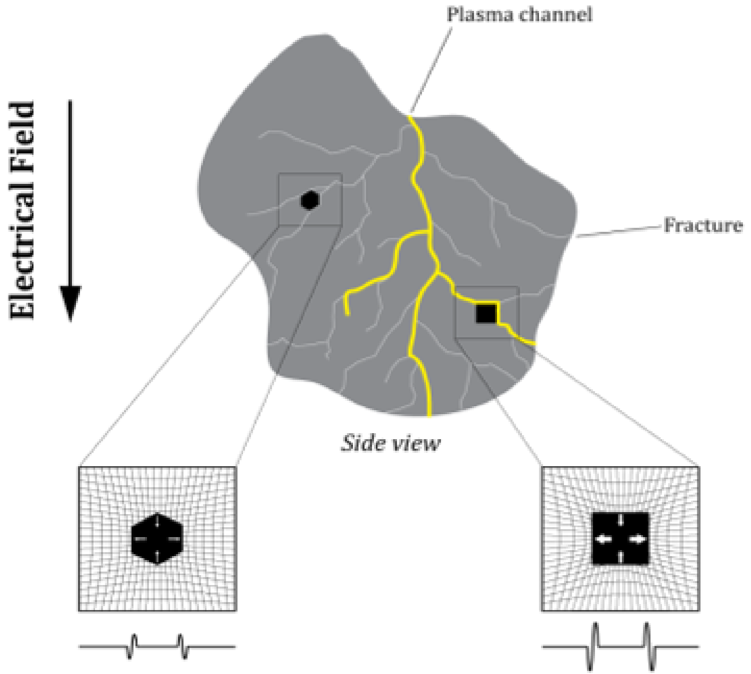
→Shock-wave and cavitation cause fragmentation over a large area



High Voltage Fragmentation

Selectivity

Electrical selectivity



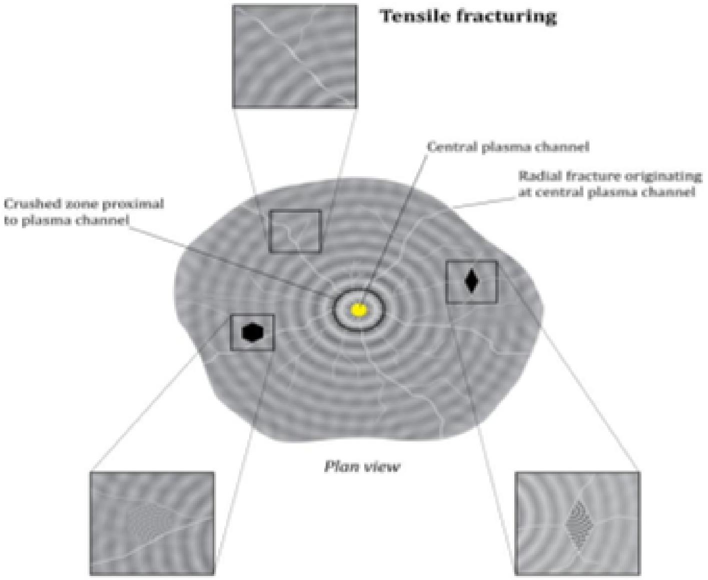
Low permittivity contrast

- *Weak field distortion along grain boundary*
- *Limited electro-strictional tension*

High permittivity contrast

- *Strong field distortion along grain boundary*
- *More pronounced electro-strictional tension*

Shockwave selectivity



Low contrast in acoustic impedance between inclusion and matrix

- *Weak wave interactions in particle*
- *Limited fracturing along grain boundaries*

High contrast in acoustic impedance between inclusion and matrix

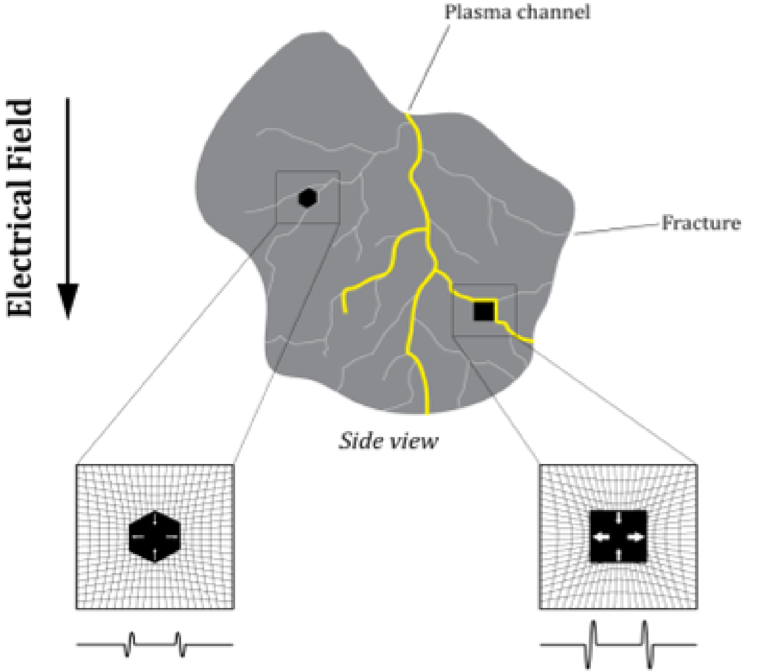
- *Strong wave interactions in particle*
- *Considerable fracturing along grain boundaries*

High Voltage Fragmentation - Discharge

Selectivity: Intergranular selective fragmentation

Field-distortion depends on dielectric properties of different components

Fragmentation develops towards zones of highest permittivity along material interfaces



Low permittivity contrast

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- *Strong field distortion along grain boundary*
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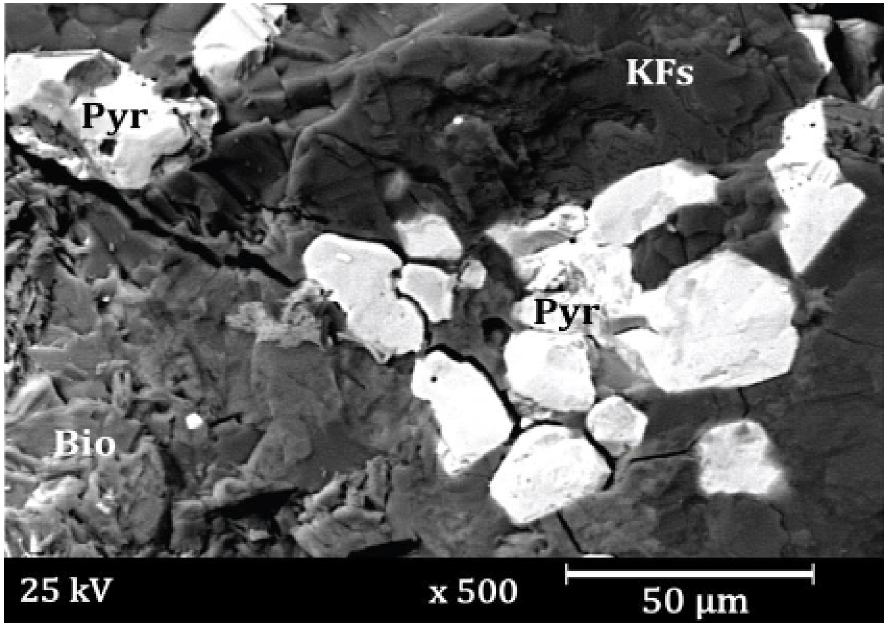
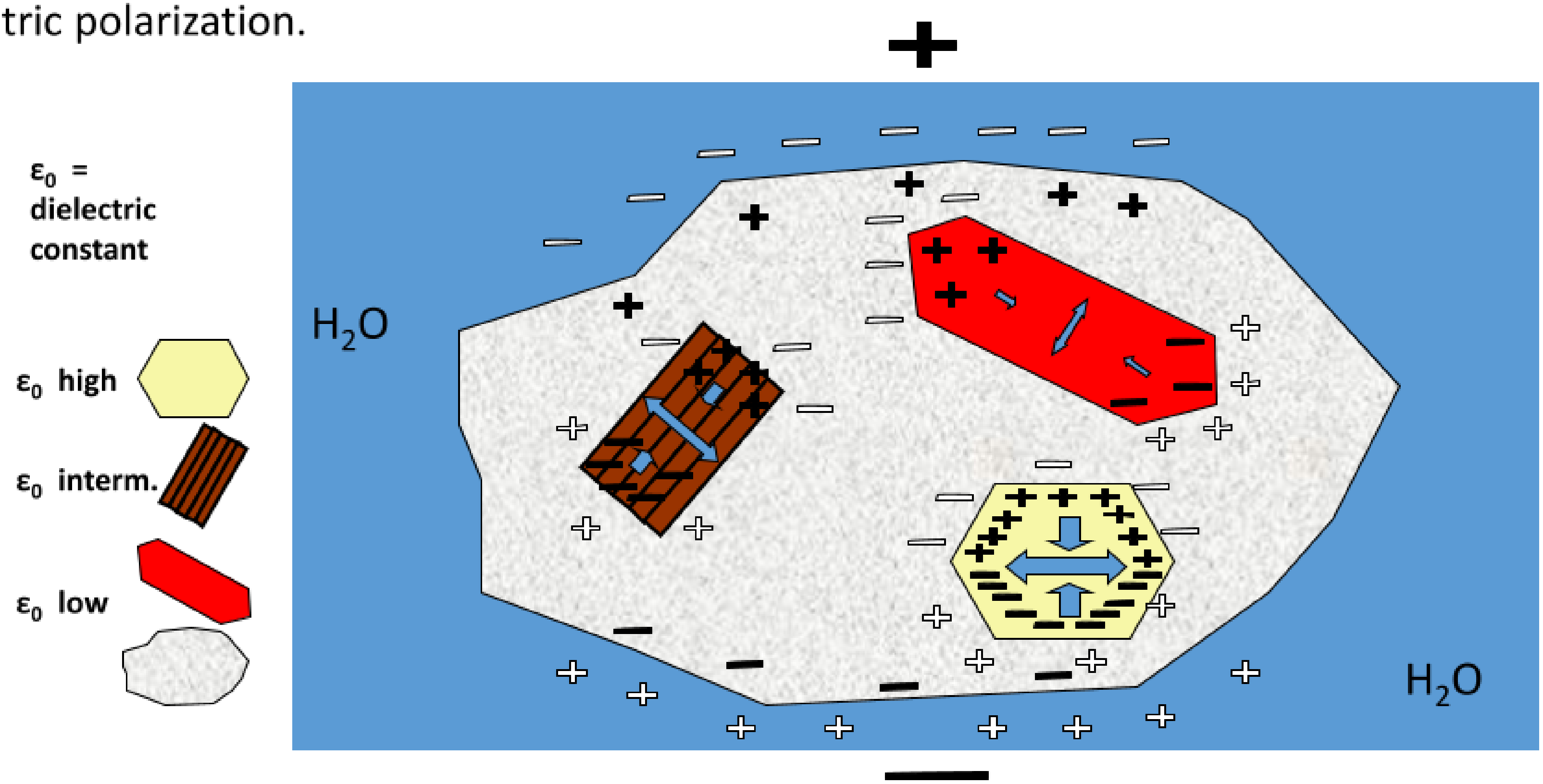


High Voltage Fragmentation

Selectivity

1. Polarization (& Electrostriction)

A **dielectric material** is an electrical insulator that can be polarized by an applied electric field. When a dielectric is placed in an electric field, electric charges do not flow through the material as they do in a conductor, but only slightly shift from their average equilibrium positions causing dielectric polarization.

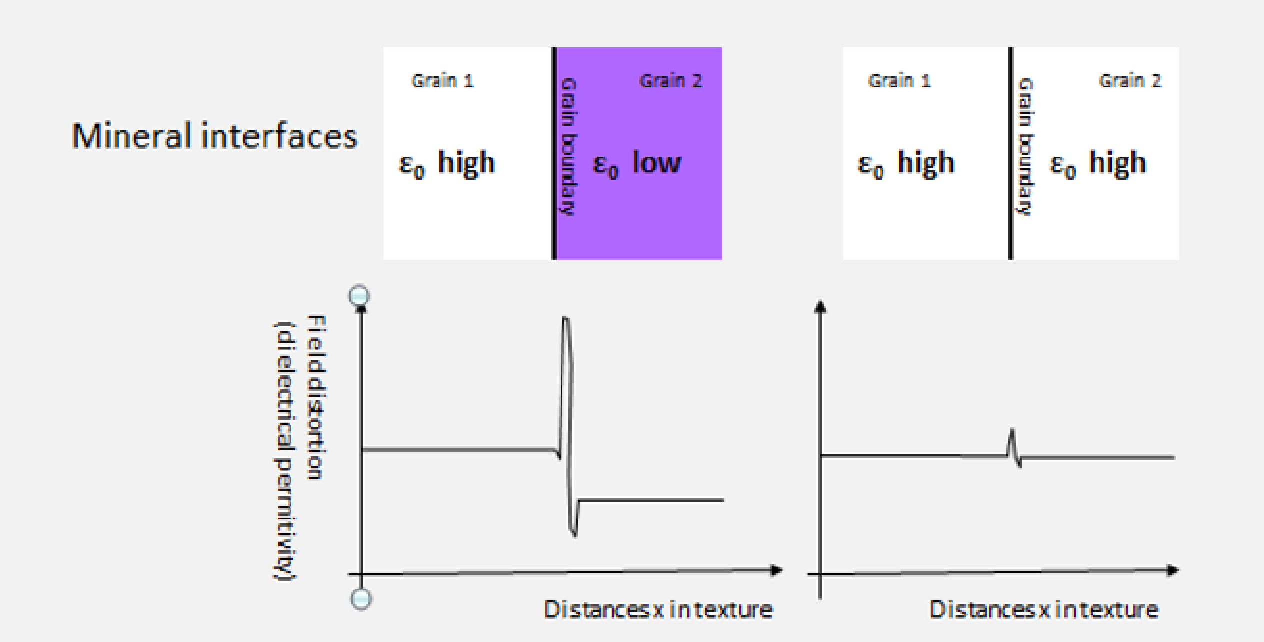


High Voltage Fragmentation

Selectivity

2. Field distortion & dielectric permitivity

When materials of different dielectric permittivity are next to one another, the strength of the field distortion at the interface varies due the difference in dielectric constants of each material.

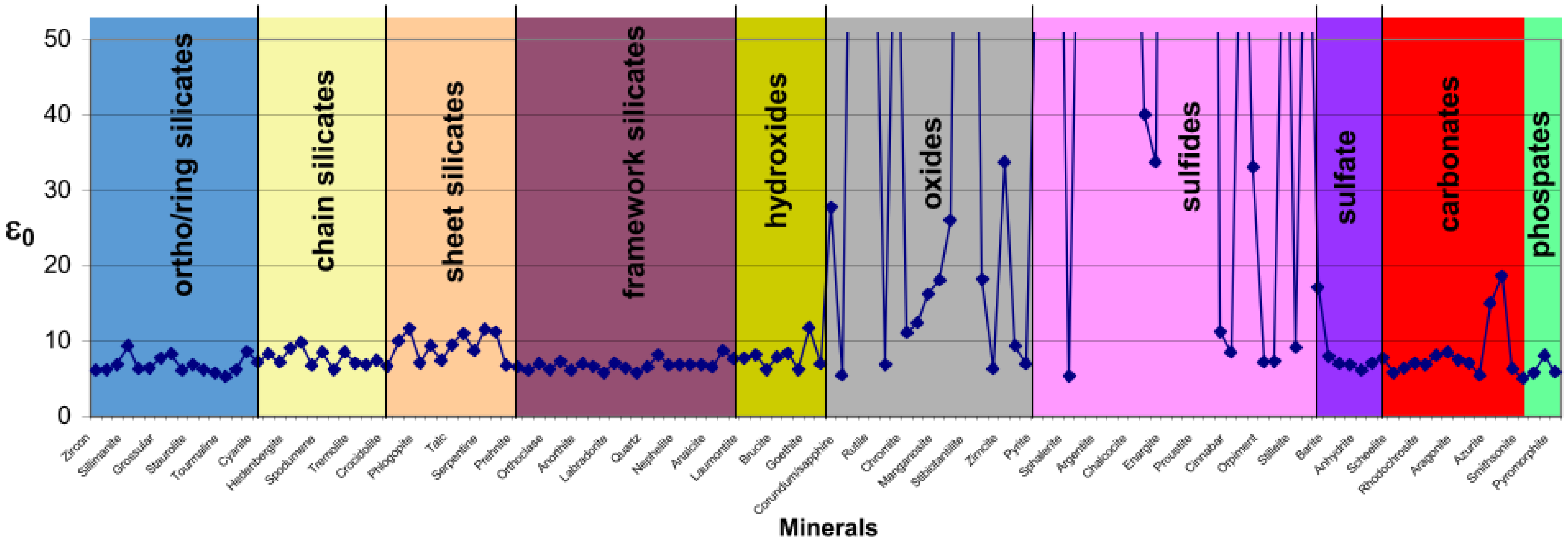


High Voltage Fragmentation

Selectivity

3. Field distortion caused by natural electrical properties of minerals

Minerals in rocks are dielectric particles and they can be considered as randomly-aligned electrical domains.



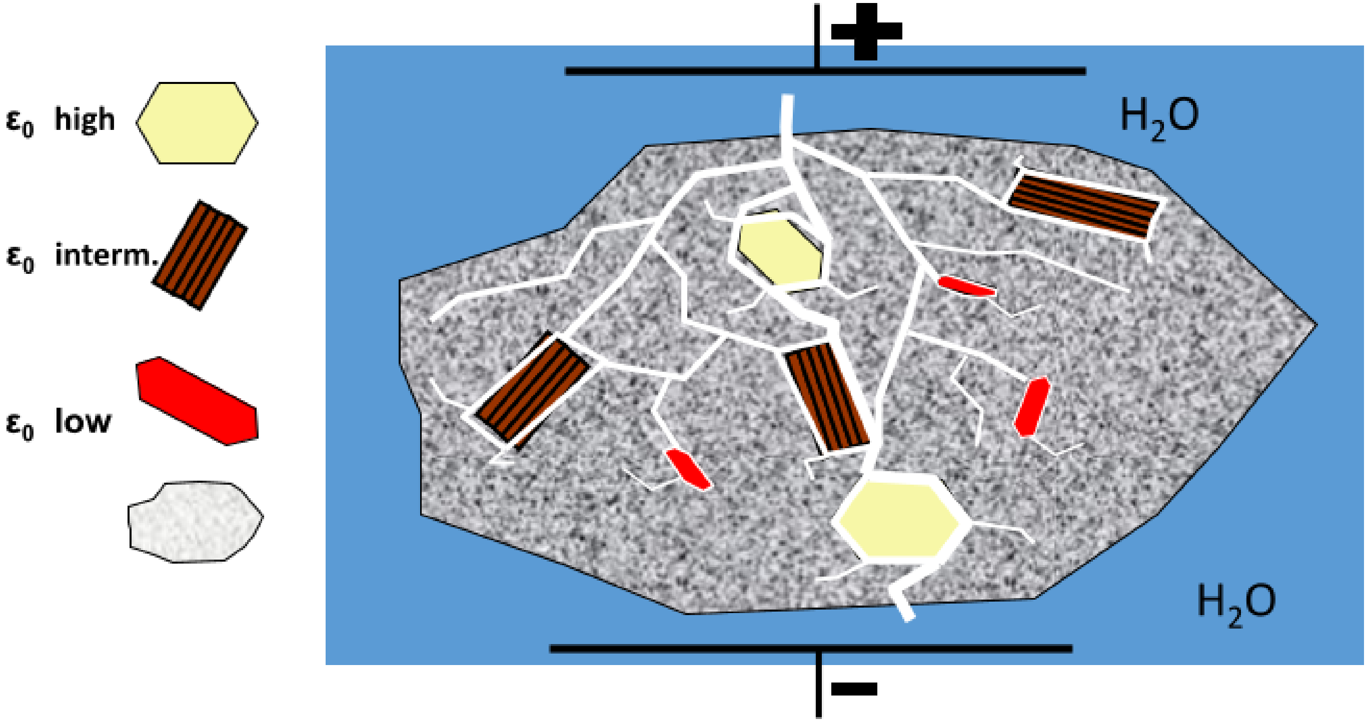
ε_0 – dielectric constant of components can be used in fragmentation

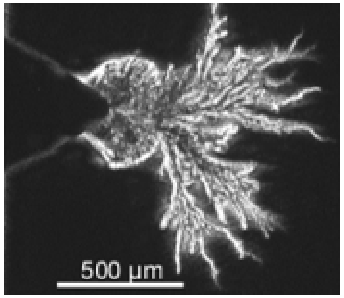
High Voltage Fragmentation

Selectivity

4. Discharge

The streamer is forced toward more conductive particles along field distortion caused by charged surfaces



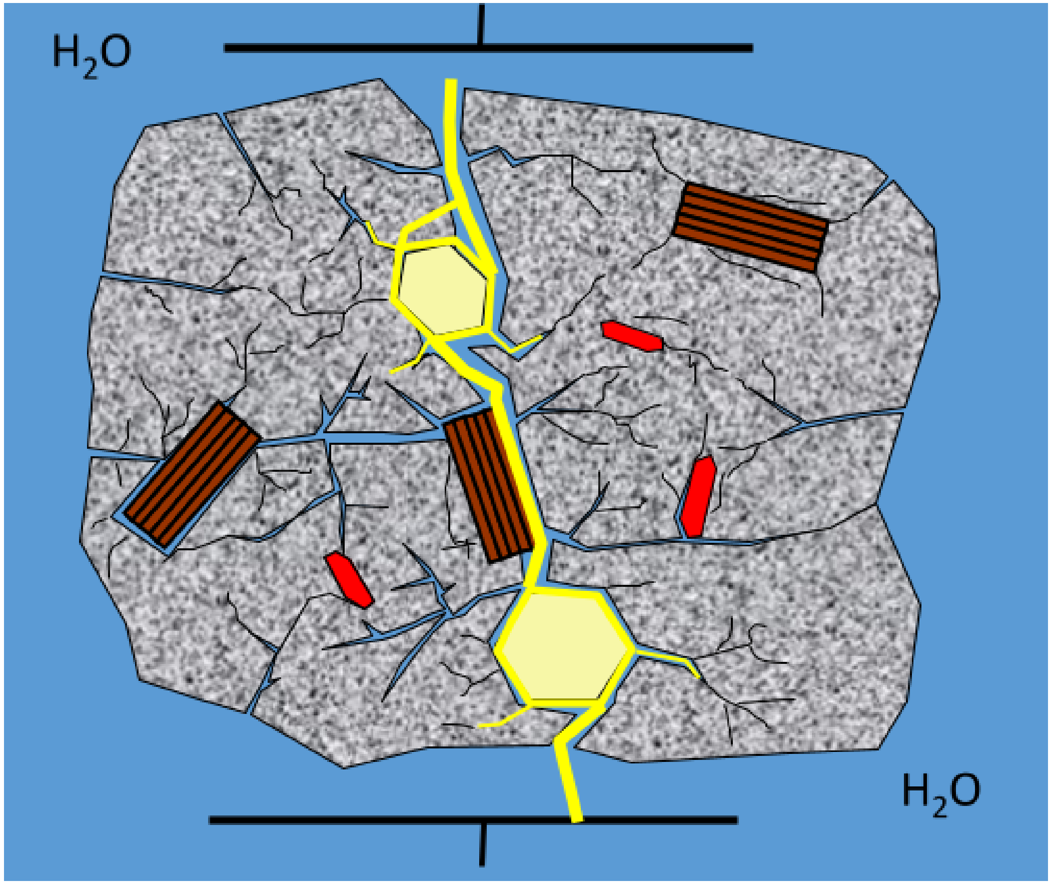


High Voltage Fragmentation

Selectivity

5. Electrical Breakdown

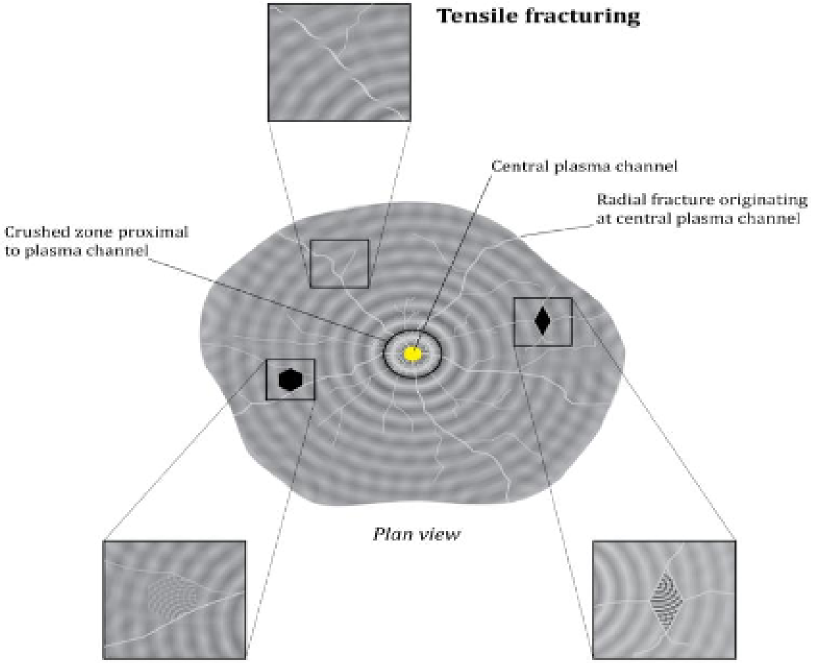
Plasma & shock wave to weaken and disintegrate



High Voltage Fragmentation - Shockwave

Selectivity: Intragranular Fragmentation

Shockwave interacts with the acoustic properties. Introduces weaknesses.



Tensile fracturing

Central plasma channel

Radial fracture originating at central plasma channel

Crushed zone proximal to plasma channel

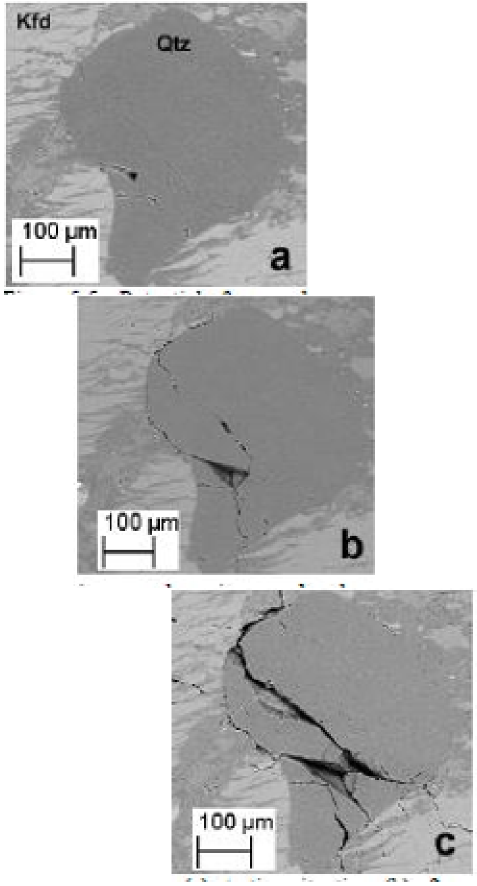
Plan view

Low contrast in acoustic impedance between inclusion and matrix

- *Weak wave interactions in particle*
- *Limited fracturing along grain boundaries*

High contrast in acoustic impedance between inclusion and matrix

- *Strong wave interactions in particle*
- *Considerable fracturing along grain boundaries*



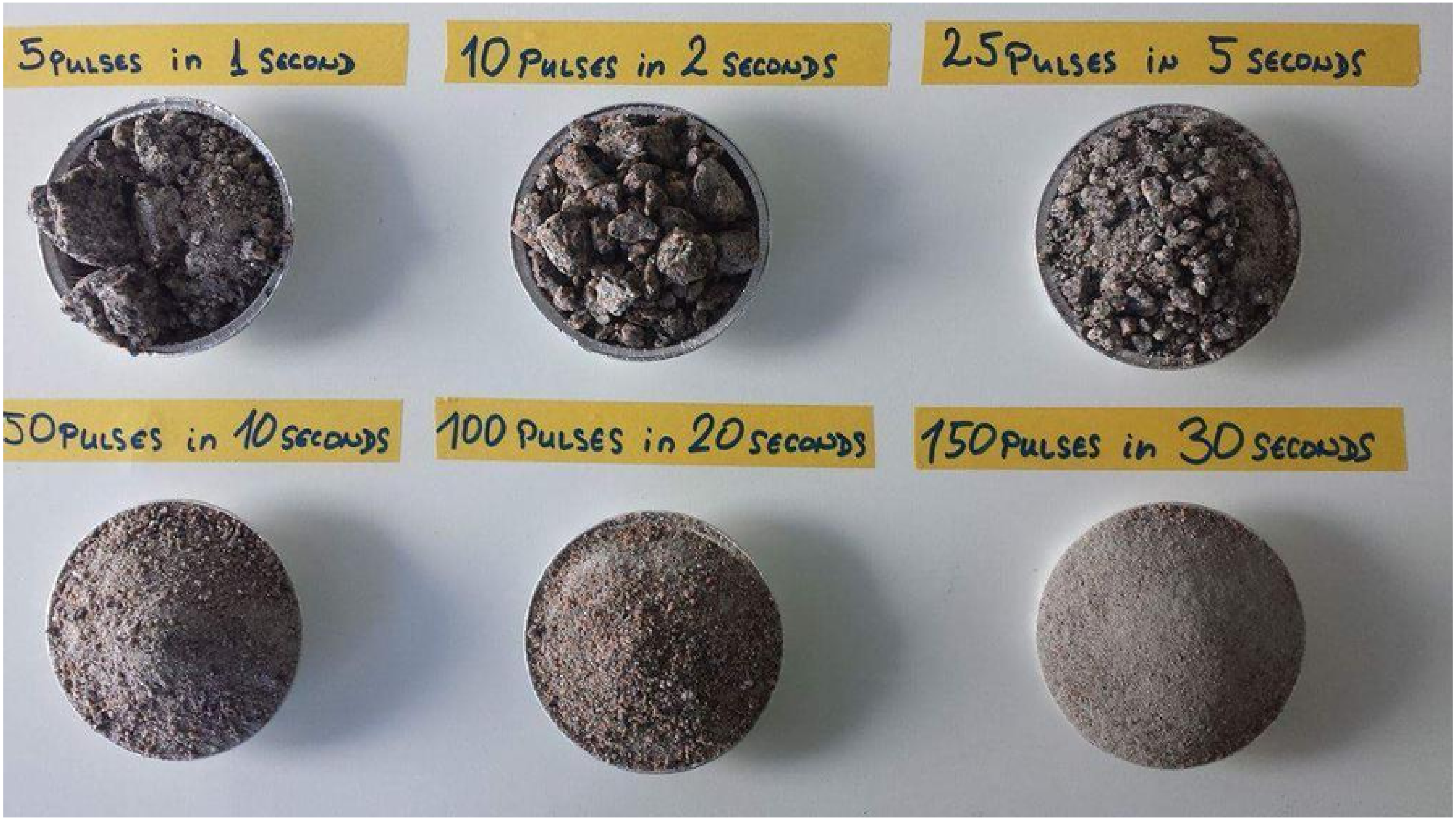
Wear reduction & Ore Weakening

High Voltage Fragmentation

Applications: Fragmentation vs Pre Weakening

- EPF processing causes two types of selective fracturing:
    1. Inter-granular selective fragmentation: the preferential fracturing along grain boundaries (plasma channel breakage).
    2. Intra-granular selective fragmentation: the preferential fragmentation of certain mineral phases (most notably quartz – acoustic breakage).
- The selectivity of the EPF process arises from two sources:
    1. Field enhancements are strongly dependent on electrical properties of minerals.
    2. Shockwave interaction with acoustic properties of minerals.

High Voltage Fragmentation

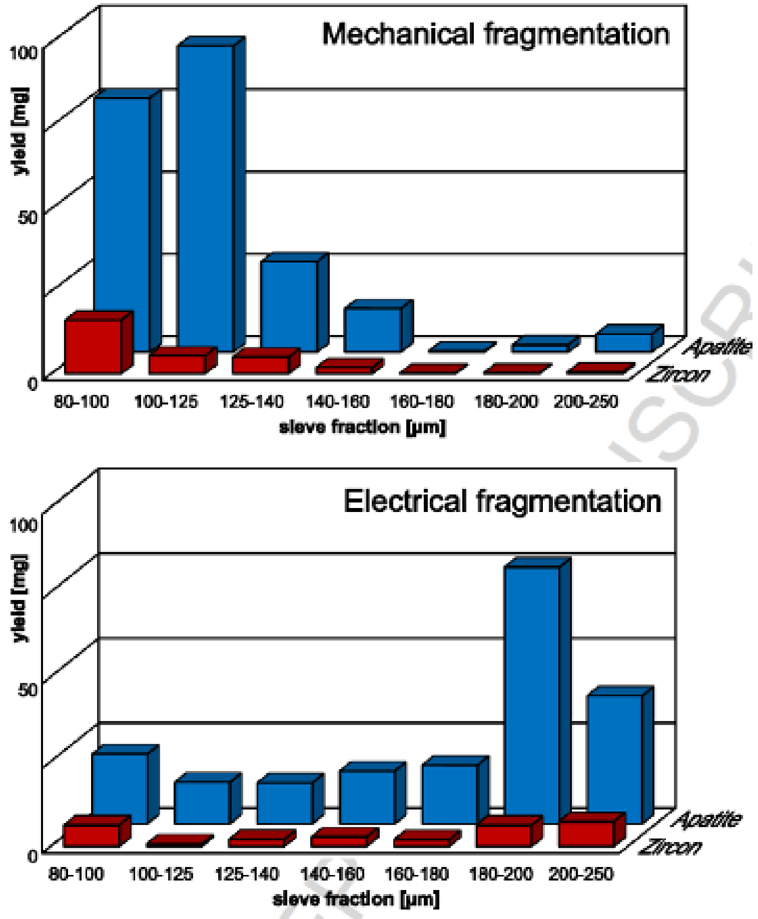


Contents

Size preservation

Apatite Cross sectional surface (Sperner *et al.*, 2014)

- Coarser mineral separate than traditional methods
- Longer minor axis value records greater preservation of outer layers – no abrasive crushing
- Longer major axis value records greater preservation of mineral length – less ‘snapping’ of mineral tips
- Findings apply to other mineral phases also, such as gemstones

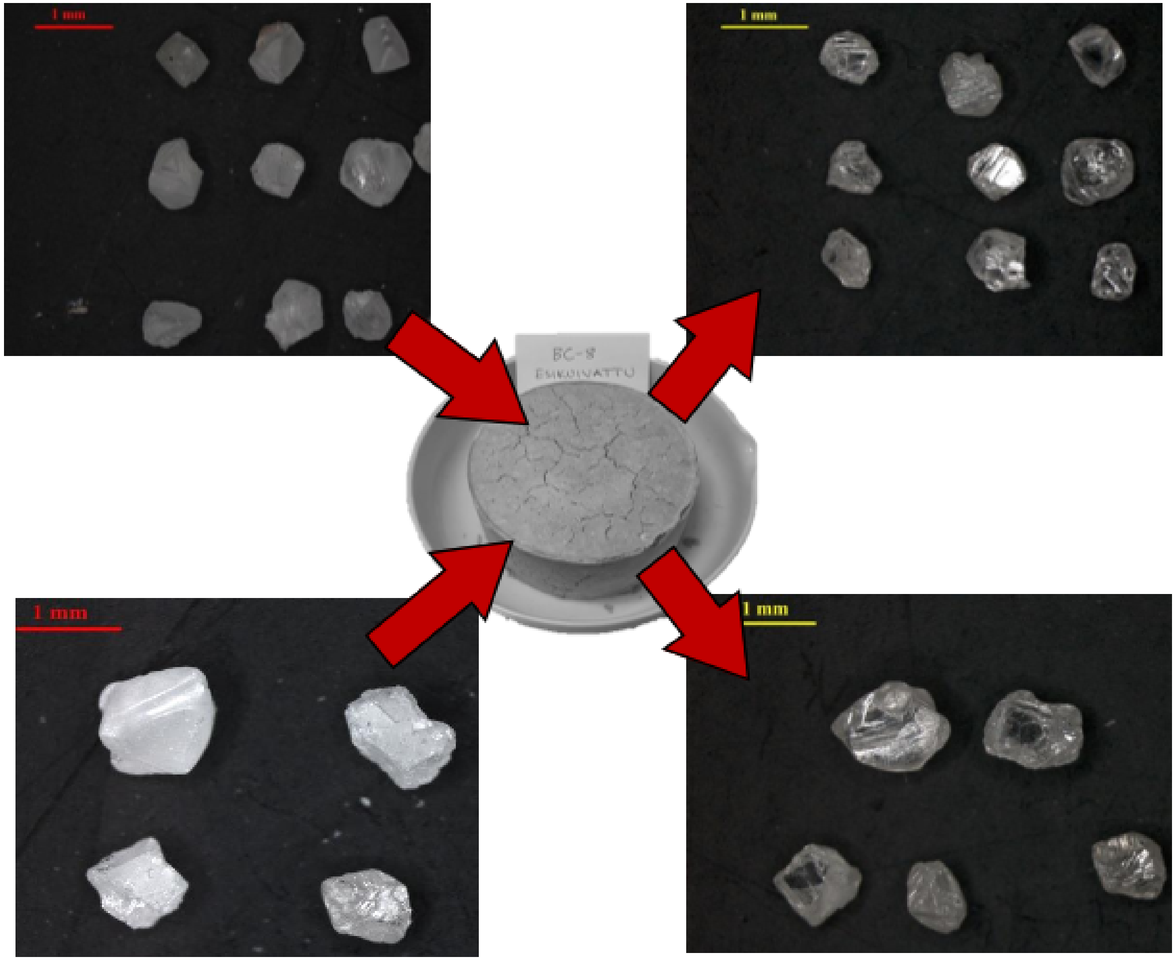


From Sperner *et al.*, 2014

Size Preservation

Diamond Exploration application

- Construction grout seeded with diamonds
- Normal EPF fragmentation
- Diamonds recovered intact and fully liberated



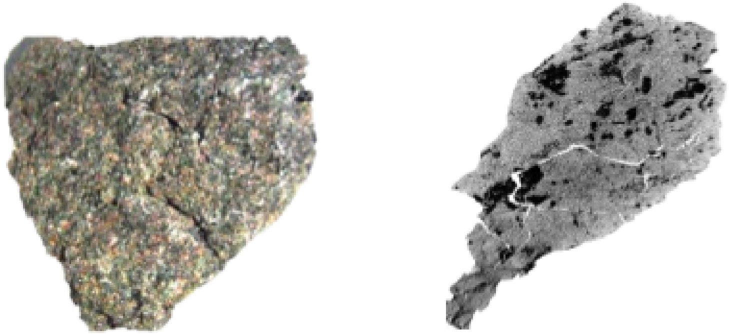
Contents

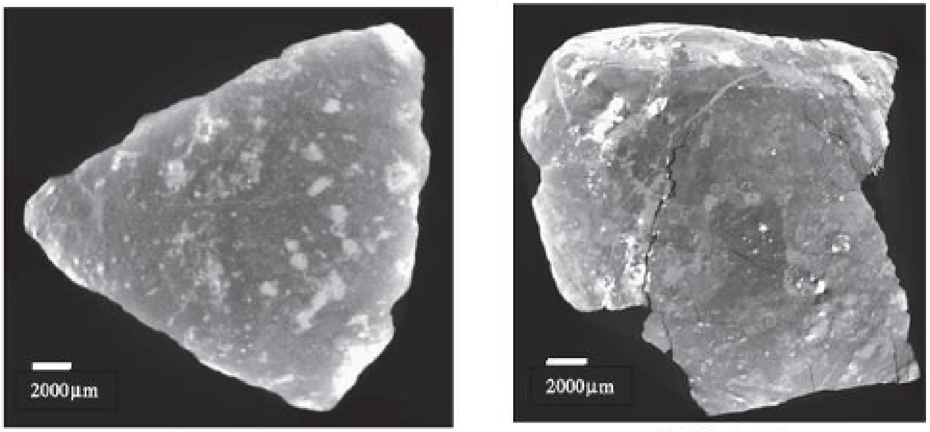
Pre Treatment

Various effects result from SELFRAG treatment

Definitions

- Weakening, surface area increase and grade splitting all occur due to partial or full fragmentation of a material
- Introduction of microcracks -> weakening and surface area increase
- Fragmentation -> grade splitting
- Treatment of the material at low energy input leads to fracturing instead of breakage
- Well constrained 'region' in which this occurs





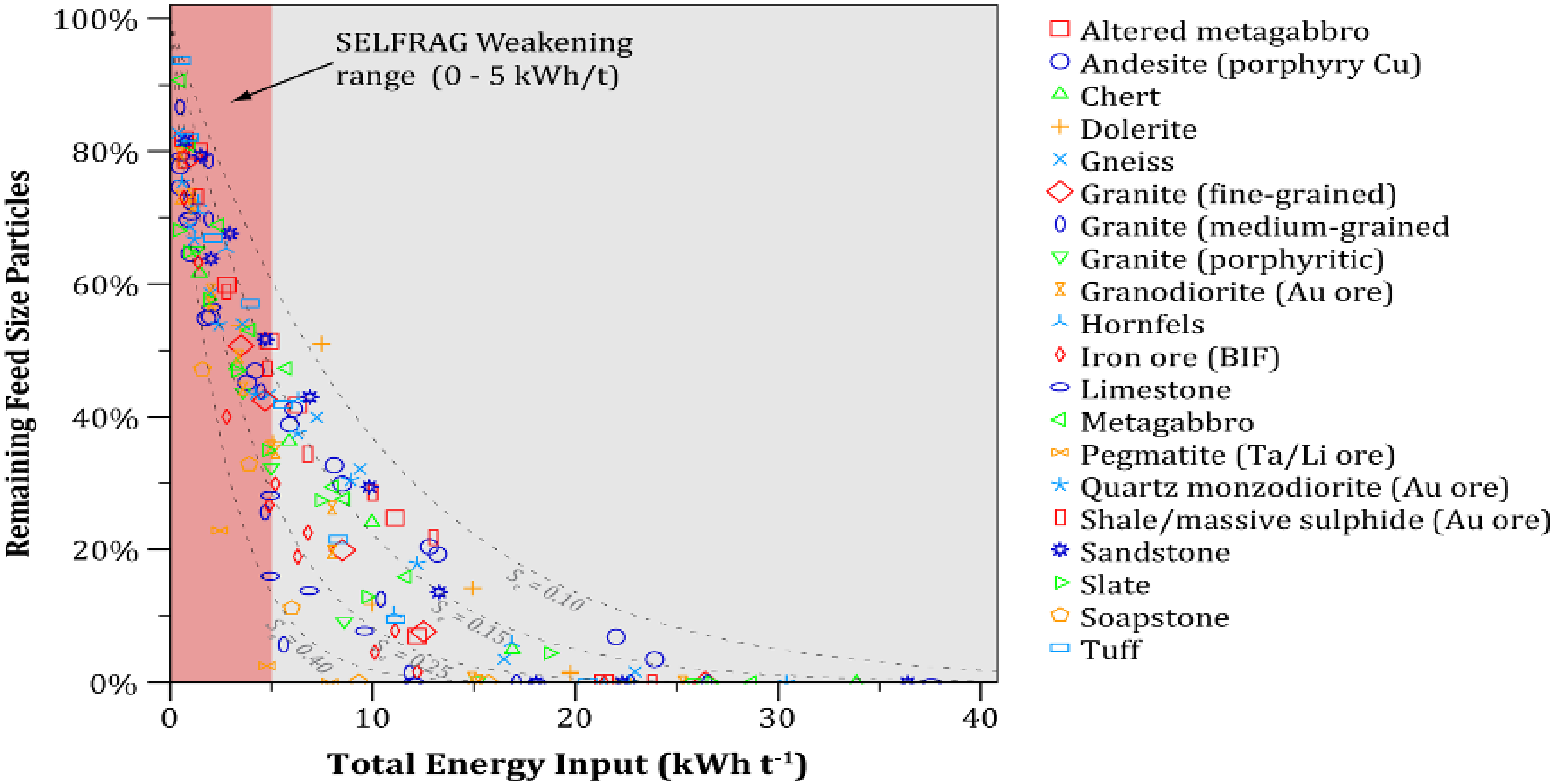
(a) Untreated

(b) Pulse-treated

Fig. 3. X-ray tomography images of gold-copper ore particles, dark lines showing cracks/microcracks.

Weakening

Pre-weakening vs Size Reduction

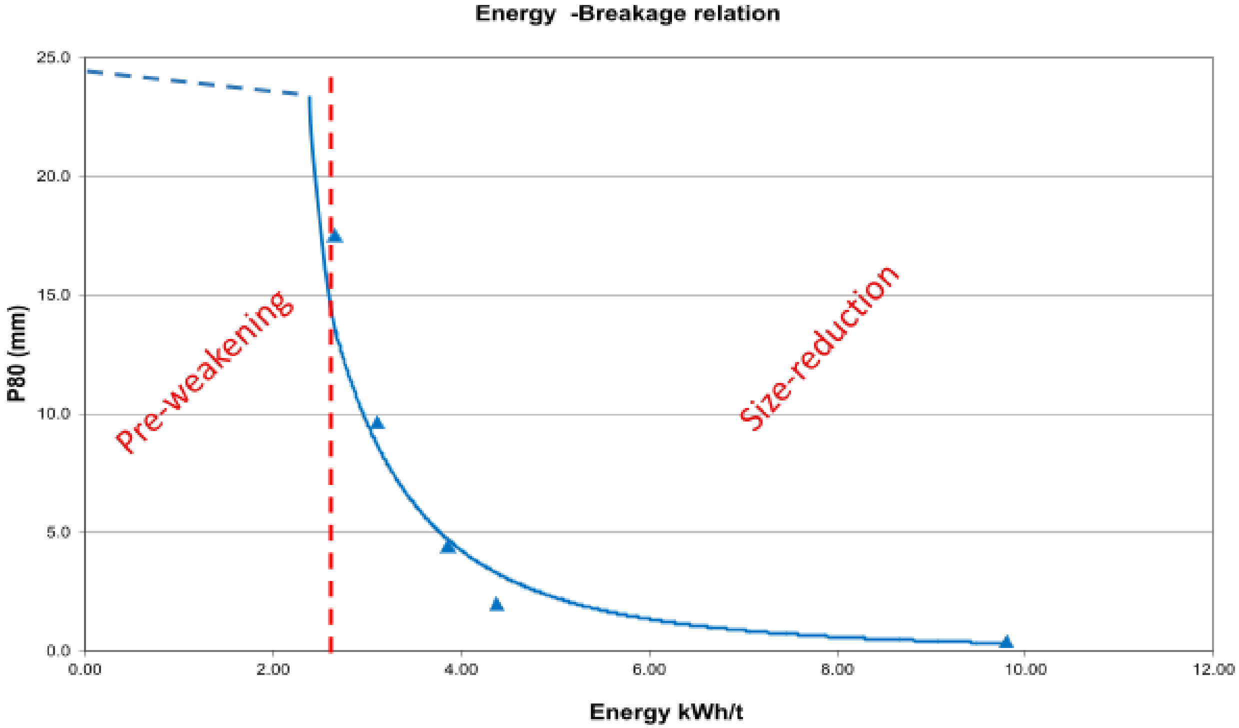


Energy input against % unbroken particles

van der Wielen, 2013

Weakening

Pre-weakening vs Size Reduction



Energy vs p80 (where 80 % of particles are below this size in mm) for SELFRAG reference granite (After van der Wielen, 2013)

Weakening

Decrease in hardness of ore after treatment

- Industry standard A*b tests and BW indices
- Results verified extensively in the literature
- Range of natural ores and synthetic materials tested
- 171% change in A*b values observed

Breakage assessment	SELFRAG Treatment	Jaw Crusher
JKMRC A*b Value¹	55.6 ± 2.5	36.6 ± 2.8
Bond Work Index²	17.5	23.0

1: Higher A*b value = softer rock; 2: Lower BWI = Softer rock

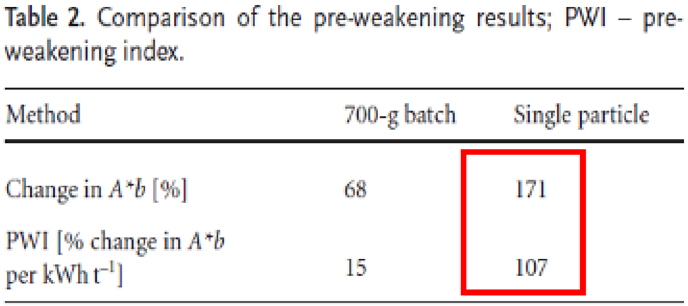
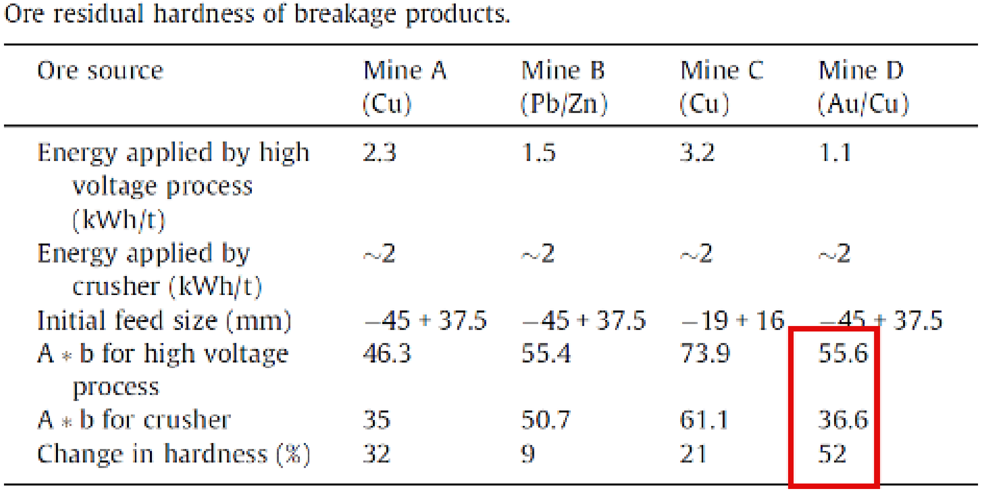


Table 2. Comparison of the pre-weakening results; PWI – pre-weakening index.

Method	700-g batch	Single particle
Change in *A*b* [%]	68	171
PWI [% change in *A*b* per kWh t^{-1}]	15	107



Ore residual hardness of breakage products.

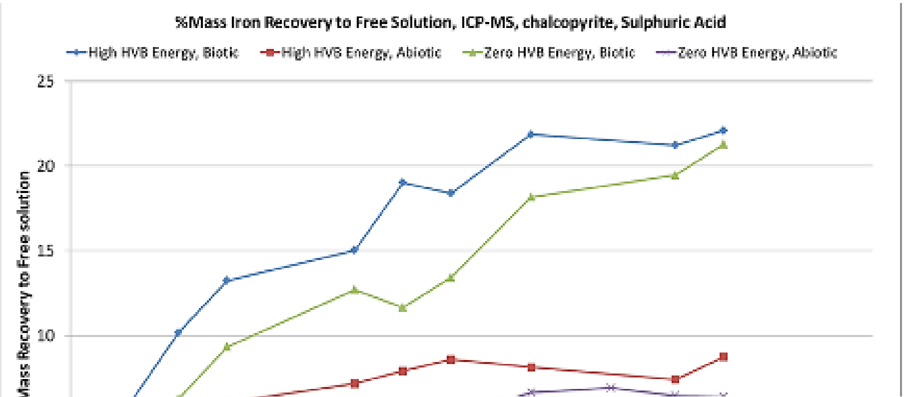
Ore source	Mine A (Cu)	Mine B (Pb/Zn)	Mine C (Cu)	Mine D (Au/Cu)
Energy applied by high voltage process (kWh/t)	2.3	1.5	3.2	1.1
Energy applied by crusher (kWh/t)	~2	~2	~2	~2
Initial feed size (mm)	−45 + 37.5	−45 + 37.5	−19 + 16	−45 + 37.5
A ∗ b for high voltage process	46.3	55.4	73.9	55.6
A ∗ b for crusher	35	50.7	61.1	36.6
Change in hardness (%)	32	9	21	52

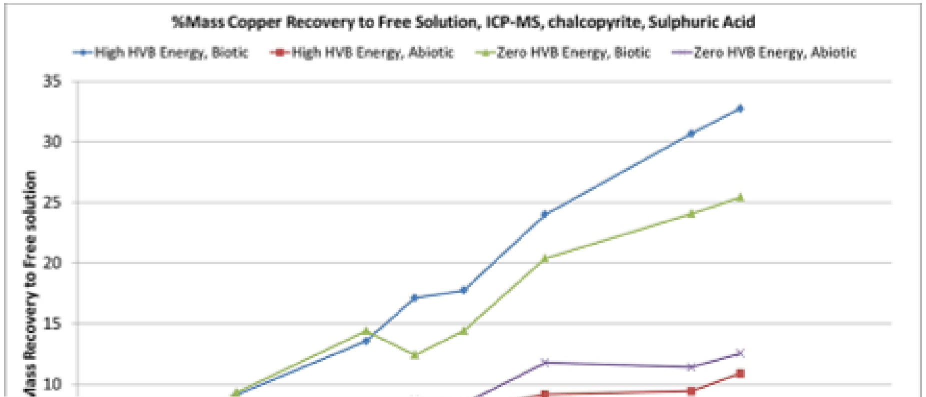
From Wang *et al.*, 2011 (JKMRC)

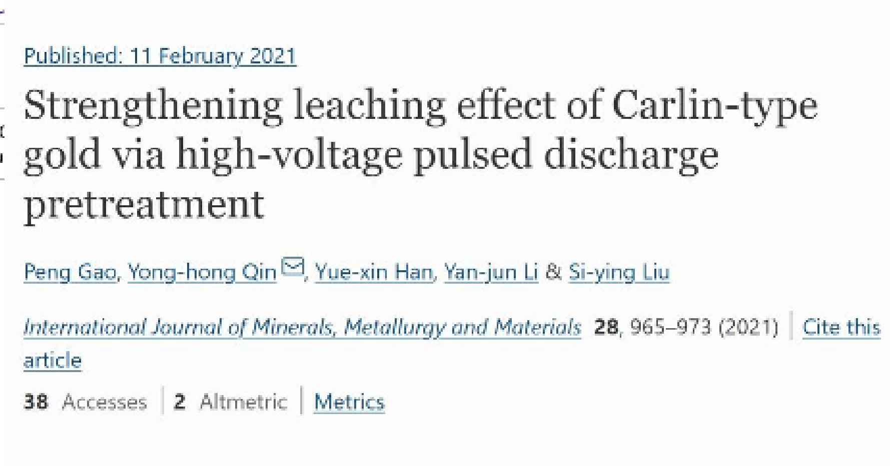
Surface Area Increase

Micro-crack formation

Dramatically increases the surface area of a rock, improving leachability







Published: 11 February 2021

Strengthening leaching effect of Carlin-type gold via high-voltage pulsed discharge pretreatment

Peng Gao, Yong-hong Qin, Yue-xin Han, Yan-jun Li & Si-ying Liu

International Journal of Minerals, Metallurgy and Materials **28**, 965–973 (2021) | Cite this article

38 Accesses | **2** Altmetric | Metrics

From Sambrook, 2014

Lightning Machines
Mineral Processing Research

Contents

Introduction to Electric Pulse Fragmentation: theory and practical applications

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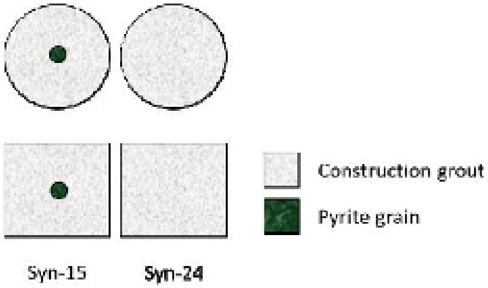
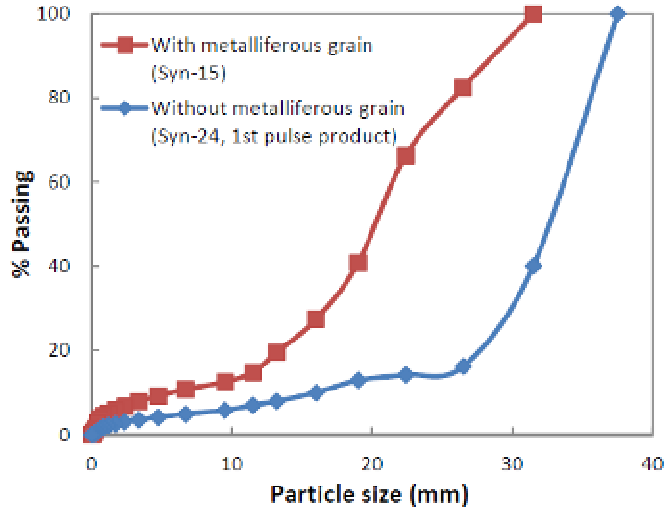
Concentration

Test work

- Research at JKMRC (Zuo et al., 2015) showed particles bearing a metallic grain showed enhanced breakage



Both in artificial…



…and natural ores

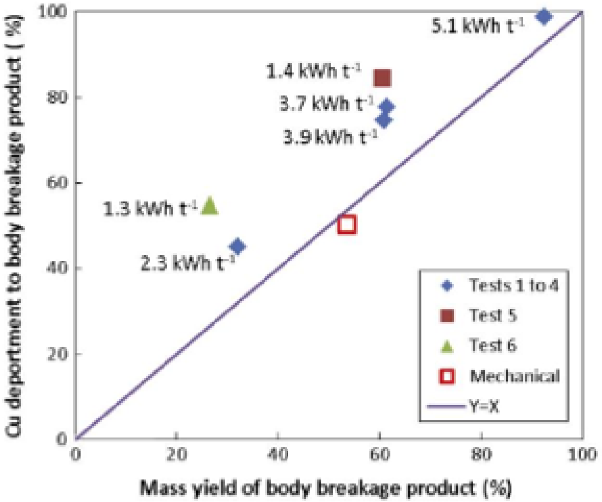
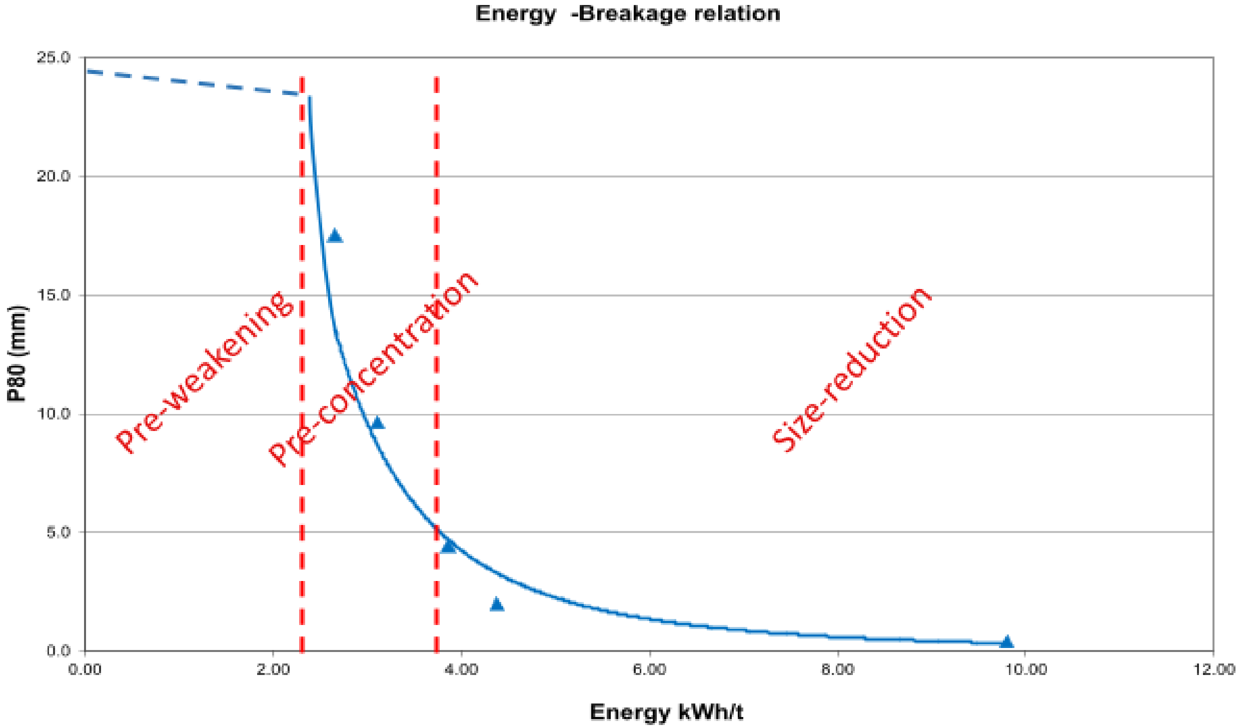


Fig. 6. Copper deportment in relation to mass yield of body breakage product in the six pre-concentration tests (the kWh t^{-1} data indicating the pulse specific energy).

After Zuo et al., 2015

Concentration

Pre-weakening v Pre-concentration v Size Reduction



Energy vs p80 (where 80 % of particles are below this size in mm) for SELFRAG reference granite (After van der Wielen, 2013)

Effects of EPF Treatment

Summary

- Coarser product particle size
  - More reflective of natural distribution
  - Useful for particle size analysis, porosity modelling etc.
  - Useful to recover key phases without breakage

- Fracture generation
  - Weakening of natural materials
  - Surface area increase

- Selective Fragmentation
  - Preferential breakage of metal rich zones
  - Concentration of metals into undersize

Contents

Introduction to Electric Pulse Fragmentation: theory and practical applications

Case Study: Scheelite Ore

Overview

Minerals Engineering 150 (2020) 106302

Contents lists available at ScienceDirect

Minerals Engineering

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journal homepage: www.elsevier.com/locate/mineng

Comparative laboratory study of conventional and Electric Pulse Fragmentation (EPF) technologies on the performances of the comminution and concentration steps for the beneficiation of a scheelite skarn ore

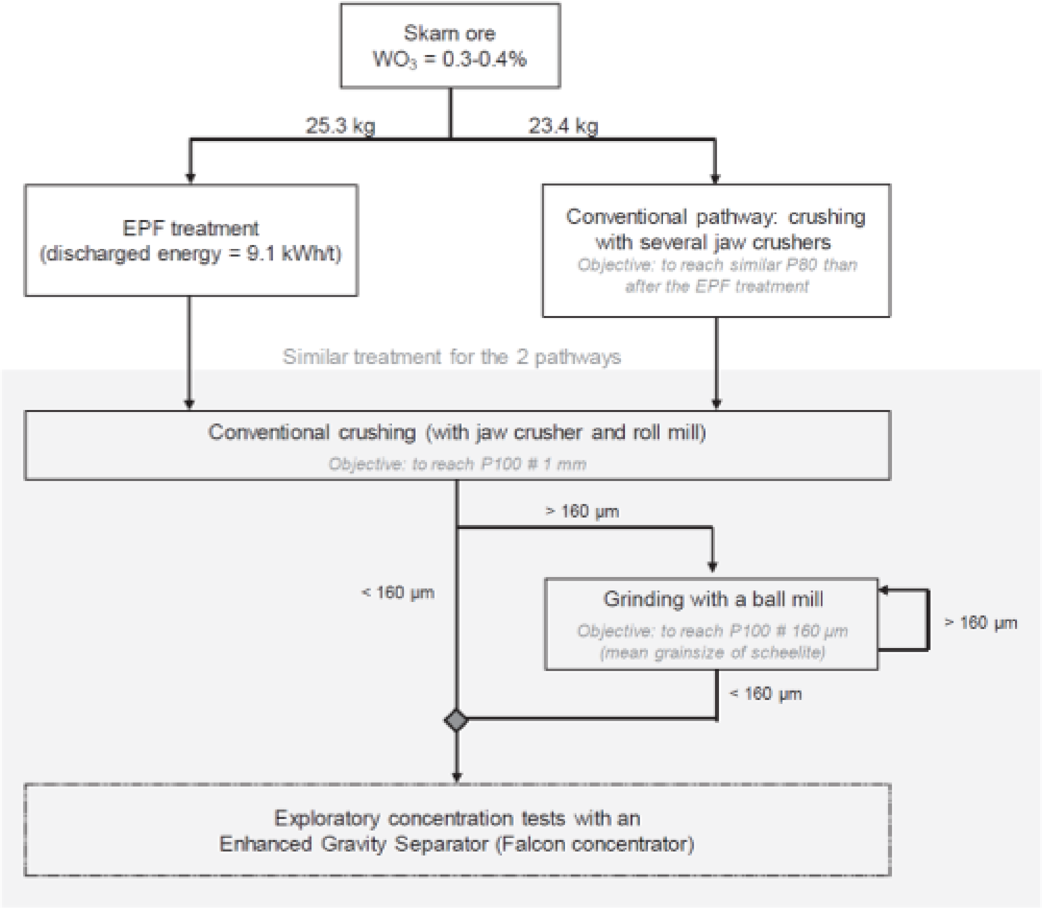
Kathy Bru[a,*], Mickaël Beaulieu[a], Rui Sousa[b], Mário Machado Leite[b], Ana Botleho de Sousa[b], Erdogan Kol[c], Jan Rosenkranz[c], Daniel B. Parvaz[d,e]

- Test work as part of FAME project (Flexible and Mobile Economic Processing Tech.)
- Batch tests on the Lab system
- Investigated a fine grained scheelite ore from a European deposit
- Overgrinding issues

Case Study: Scheelite Ore

Overview

- Treated W (scheelite) ore at a range of EPF energies and determined psd and upgrading for these
- Blank sample stage crushing to reach similar p80 to selected Single pass EPF sample (9.1 kWh/t)
- Assessed WO_3 content in fine fractions
- Assessed grindability of treated and untreated ore



Skarn ore
WO_3 = 0.3-0.4%

25.3 kg

23.4 kg

EPF treatment
(discharged energy = 9.1 kWh/t)

Conventional pathway: crushing with several jaw crushers
Objective: to reach similar P80 than after the EPF treatment

Similar treatment for the 2 pathways

Conventional crushing (with jaw crusher and roll mill)
Objective: to reach P100 # 1 mm

> 160 µm

< 160 µm

Grinding with a ball mill
Objective: to reach P100 # 160 µm (mean grainsize of scheelite)

> 160 µm

< 160 µm

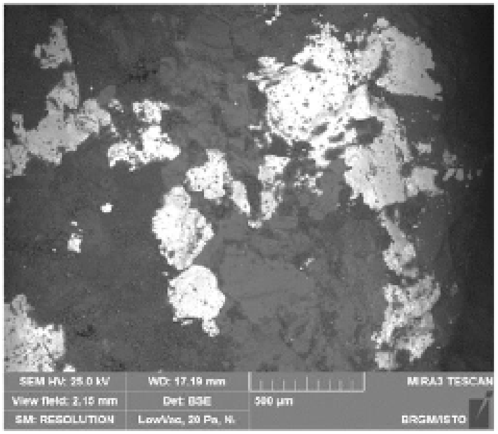
Exploratory concentration tests with an
Enhanced Gravity Separator (Falcon concentrator)

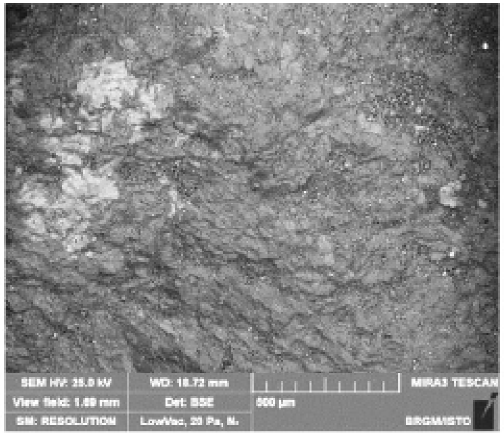
Fig. 2. Methodology implemented for assessing the influence of an EPF treatment on the comminution and concentration performances.

Case Study: Scheelite Ore

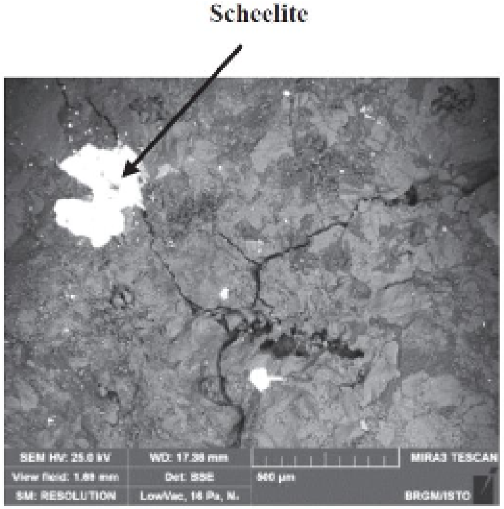
Weakening

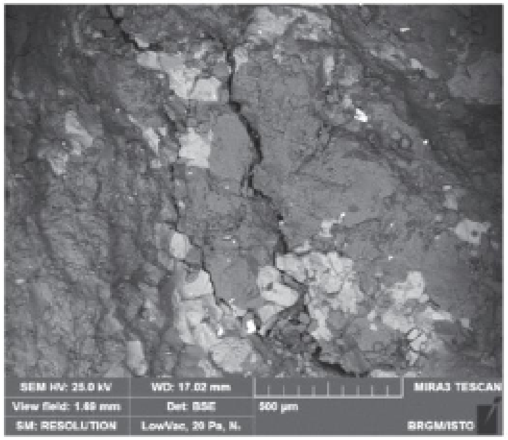
0 kWh/t



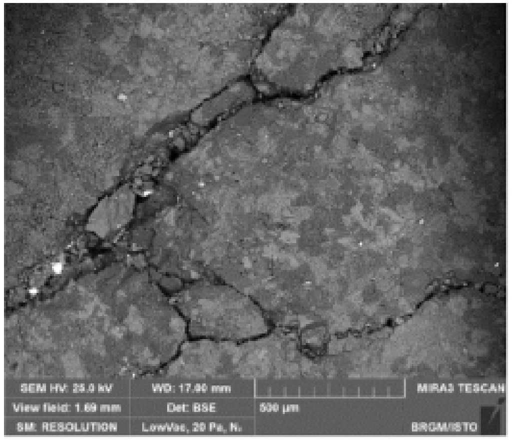


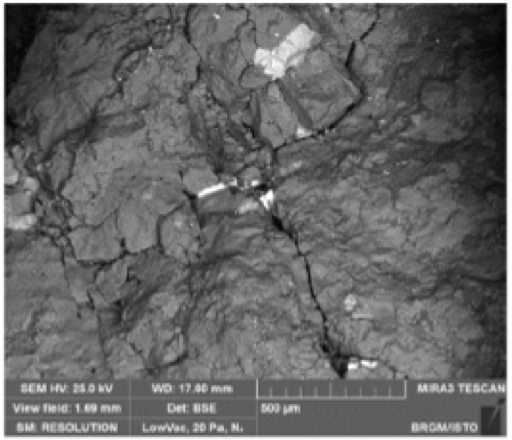
1.5 kWh/t





9.1 kWh/t





Case Study: Scheelite Ore

Weakening

- Overall reduction in grinding energy after EPF
- Reduction in losses to -10micron during ball milling
- Total energy consumption 19.7 vs 16.0 kWh/t for EPF vs traditional – 3.7kWh/t increase
- Recovery rates similar

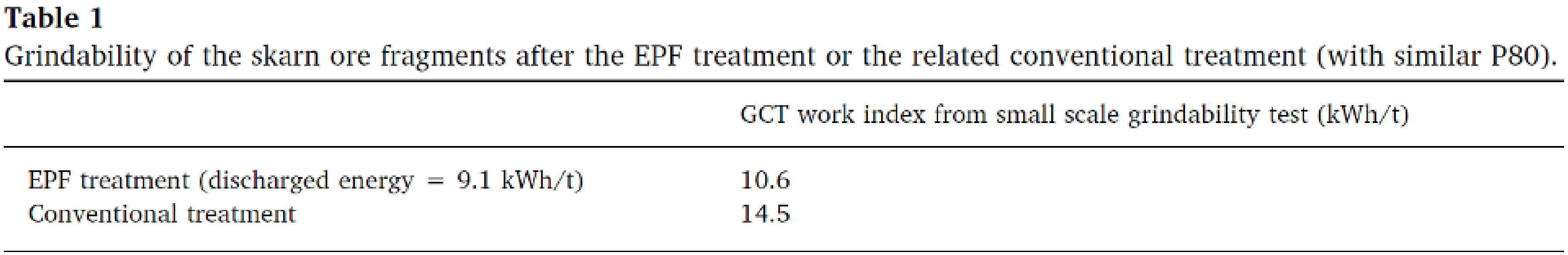


Table 1
Grindability of the skarn ore fragments after the EPF treatment or the related conventional treatment (with similar P80).

	GCT work index from small scale grindability test (kWh/t)
EPF treatment (discharged energy = 9.1 kWh/t)	10.6
Conventional treatment	14.5

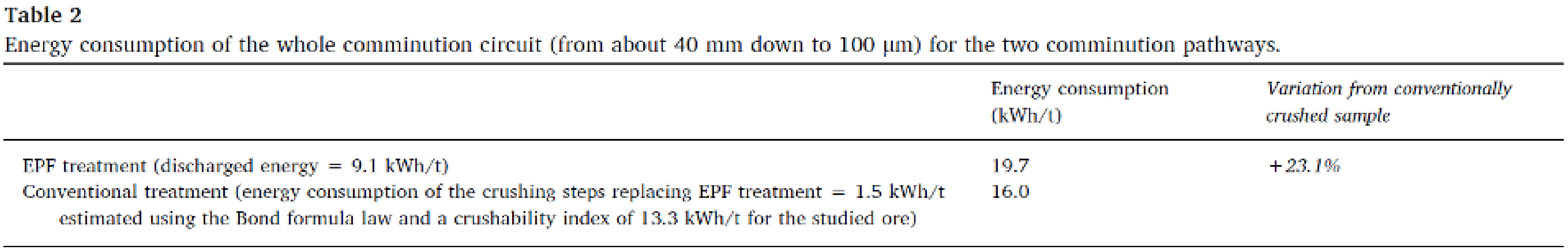


Table 2
Energy consumption of the whole comminution circuit (from about 40 mm down to 100 μm) for the two comminution pathways.

	Energy consumption (kWh/t)	*Variation from conventionally crushed sample*
EPF treatment (discharged energy = 9.1 kWh/t)	19.7	*+23.1%*
Conventional treatment (energy consumption of the crushing steps replacing EPF treatment = 1.5 kWh/t estimated using the Bond formula law and a crushability index of 13.3 kWh/t for the studied ore)	16.0	

Case Study: Scheelite Ore

Concentration

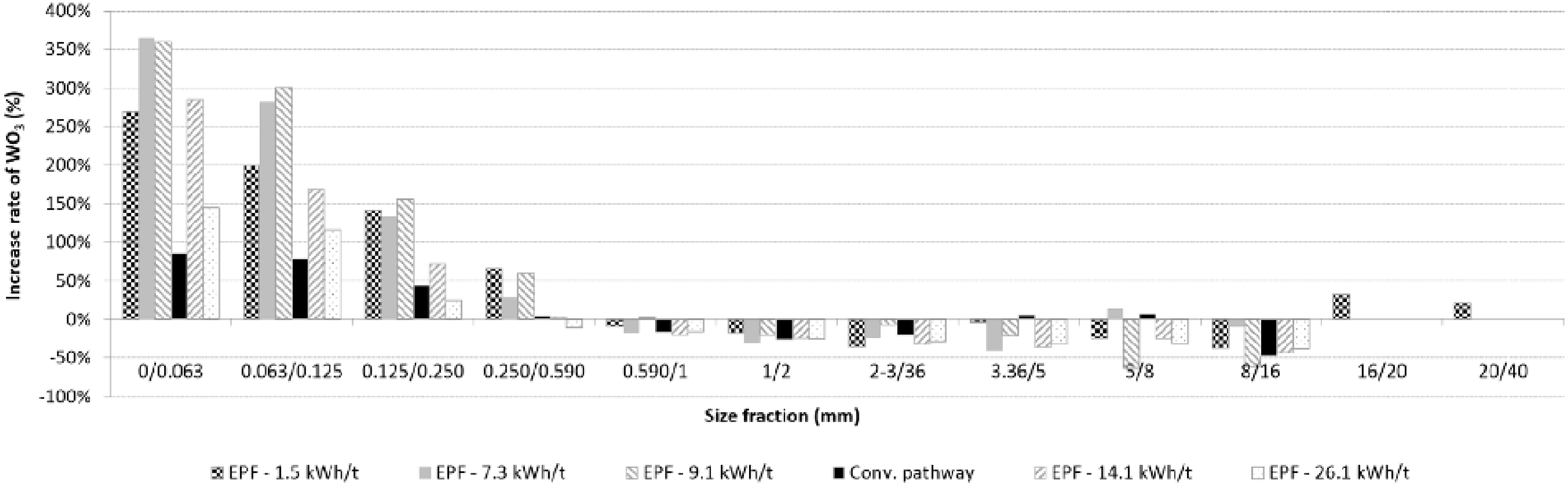


Fig. 8. Increase rate of WO_3 content for EPF treatment performed at various discharged energies and for the conventional pathway (as described in Fig. 2).

- Increase in WO_3 in smaller size fractions after EPF treatment
- effect reduced at higher energies

Case Study: Scheelite Ore

Concentration

- WO_3 distribution plotted against cumulative passing size directly after EPF treatment.
- 50% of WO_3 was concentrated in ~22% of the mass @~9.1 kWh/t
- EPF shows the ability to concentrate value in a small amount of mass at the cost of recovery.

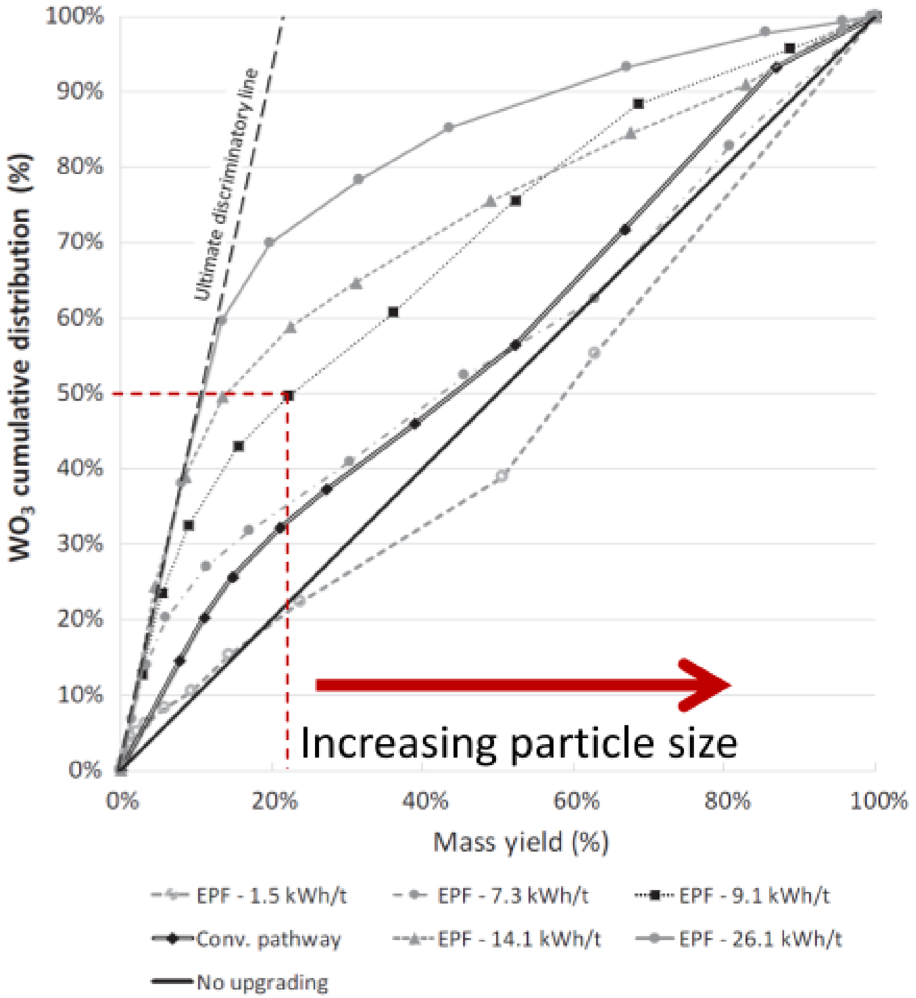


Fig. 10. WO_3 cumulative distribution, from fine to coarse size fractions, after EPF treatment performed at various discharged energies and for the conventional pathway (as described in Fig. 2).

Case Study: Scheelite Ore

Conclusions

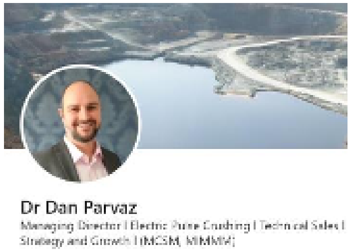
- Treatment introduces visible fractures to ore, localised at metal bearing minerals.
- EPF treatment led to increased WO_3 in fine fractions
- Overall reduction in fines
- Grindability improvement from 14.5 kWh/t -> 10.6 kWh/t for 9.1kWh/t EPF energy (5.2kWh/t difference between pathways)
- Energy Consumption increase from 16.0 to 19.7 kWh/t
- Improved WO_3 concentrate grade for similar recovery
- EPF pre treatment an additional tool, not replacement for conventional methods?
- No one size fits all process route for EPF – sorting needed after EPF – density usually easiest.

It doesn't just work on rocks…

Summary

& Take Home Message

- EPF is a useful tool and has applications in weakening rock and selectively liberating & concentrating metallic minerals
- Potential to improve grindability by 100 %
- Can concentrate value in fine fractions at an early stage
- Sorting needed after EPF stage to exploit the selectivity of the treatment
- Not a 1:1 replacement for existing plant, but enhances performance of conventional equipment
- Research still in it’s infancy and more work systematic needs to be done on a range of materials and equipment settings



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Lightning Machines

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