Physical and Morphological Characteristics of Iron Ore and their Routes of Comminution

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OBJECTIVE

Answer the questions:

Is there an association between the properties of iron ore deposits and the design of the comminution circuit?

If so, what is it?

CONTENT

- Relevance of comminution
- Common types of equipment
- Properties of iron ore-bodies
- Ore hardness
- Grinding circuit designs

Comminution Relevance

- Increasing world trend to process low grade Fe deposits
- Comminution circuit Capex to produce a 10 mtpa Fe concentrate facility could be as high as US$ 1 billion
- Comminution circuit operating costs can account for 65% of total costs

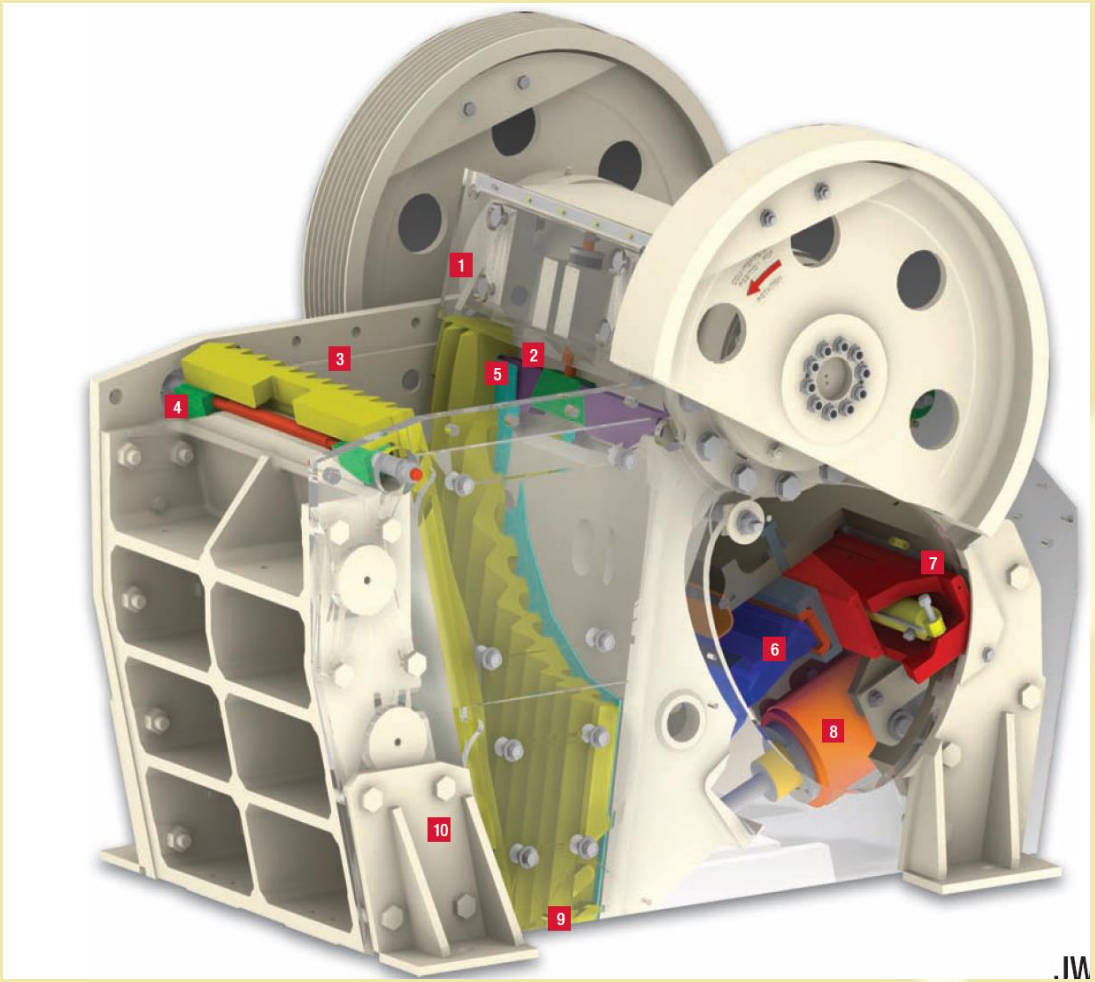
  – ***Comminution circuit is a major contributor to project financial viability***

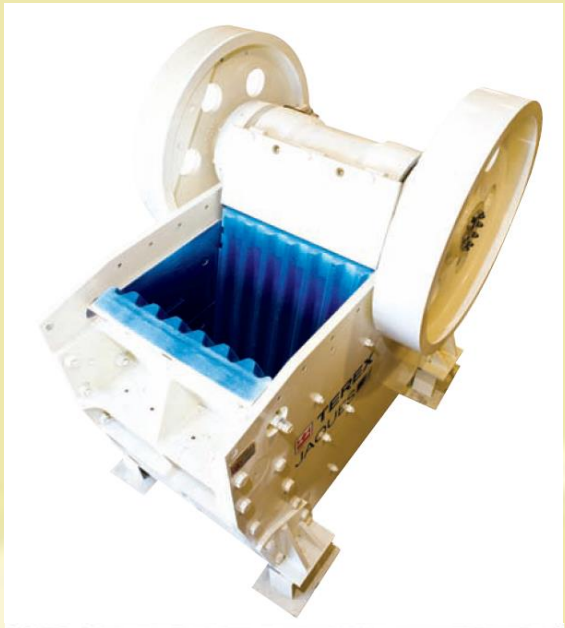
Comminution Equipment

- Crushers
- High Pressure Grinding Rolls
- Tumbling mills
  - Autogenous and Semi-autogenous (AG/SAG)
  - Ball Mills
- Stirred mills
  - Vertical
  - Horizontal

Jaw Crushers

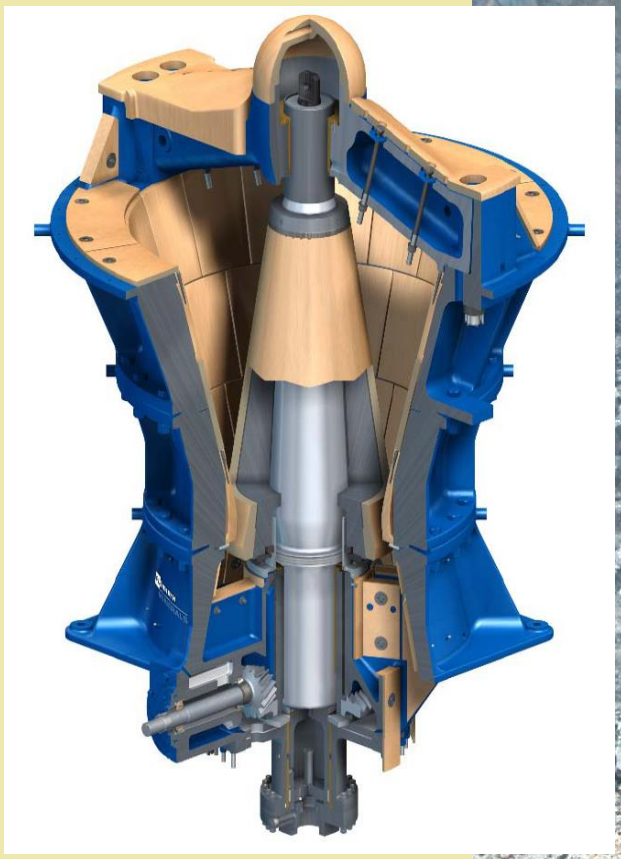
1200-1500 tph





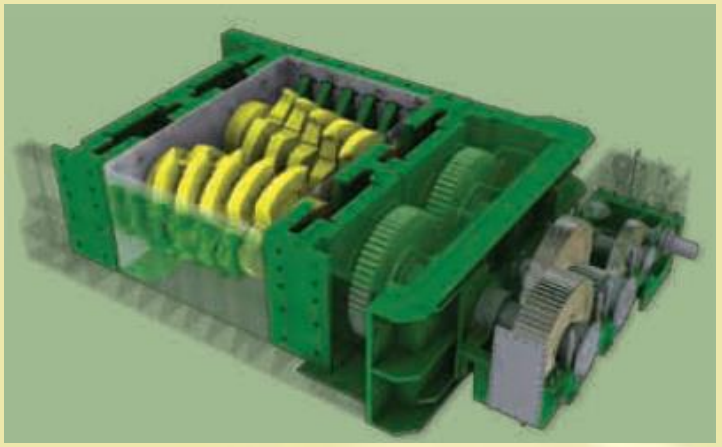
Gyratory Crushers

5000-7000 tph

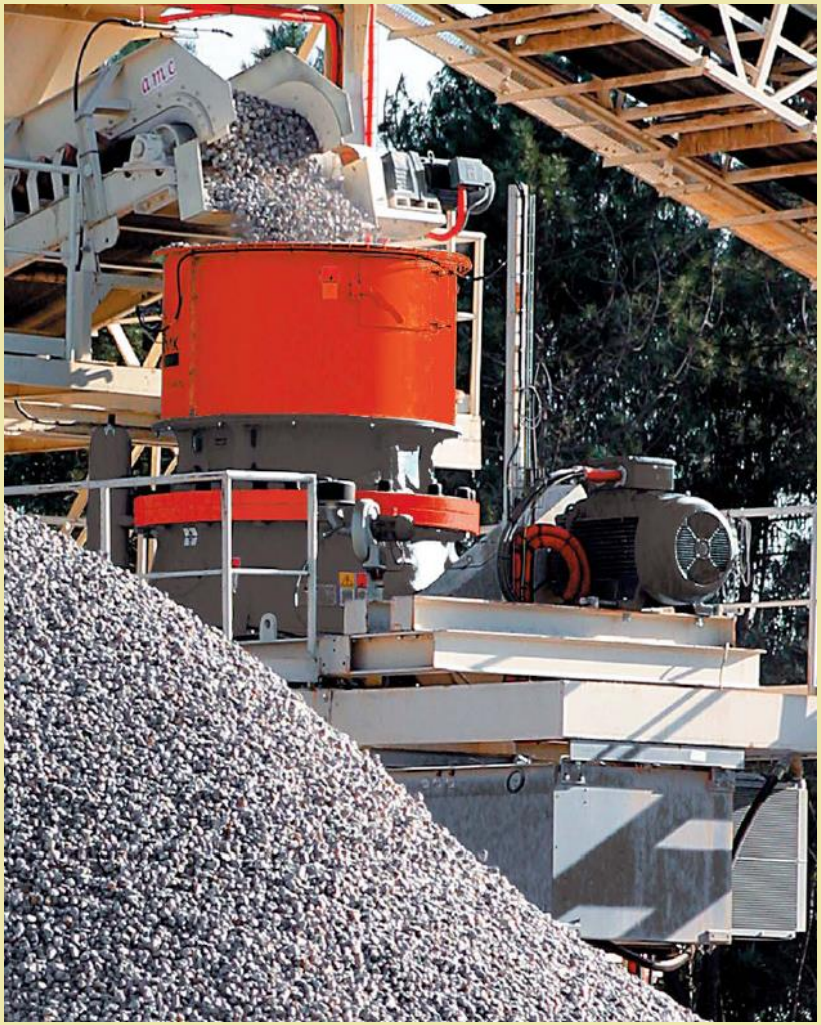


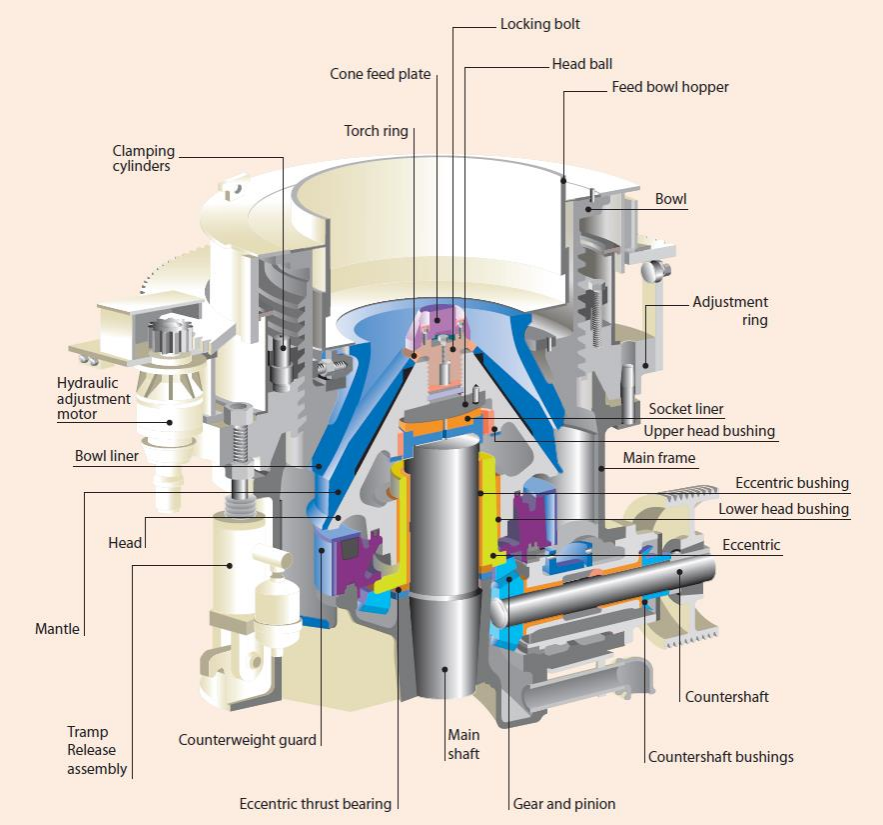
Toothed Roll Crushers

5000-7000 tph



Cone Crushers



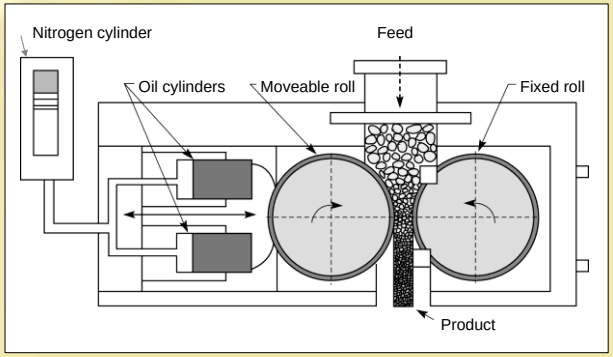


Secondary: 1200-1500 tph

Tertiary: 400-500 tph

High Pressure Grinding Rolls

Tertiary/quaternary: 2500-3200tph



AG/SAG Mills

Operating:

Up to 40ft diameter

24 MW motor

Under construction:

40ft x 36ft

28MW motor

Iron ore

On order:

42ft x 22ft

28 MW motor

Ball Mills

Operating:

Up to 27ft diameter

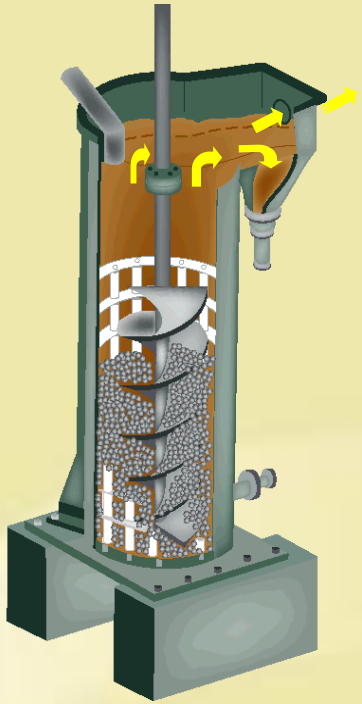
18 MW motor

Under construction:

28ft diameter

22 MW motor

Tower & Vertimills



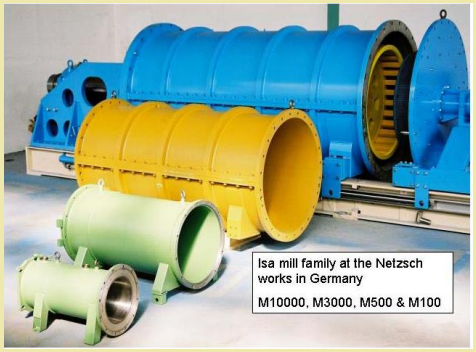
Up to 2.25 MW motor

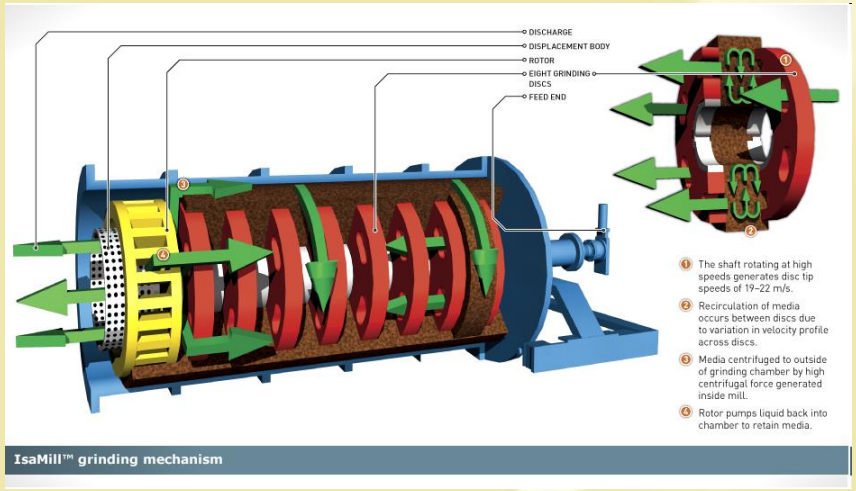
Down to 20 microns

IsaMill

Up to 3MW motor

Down to 10 microns

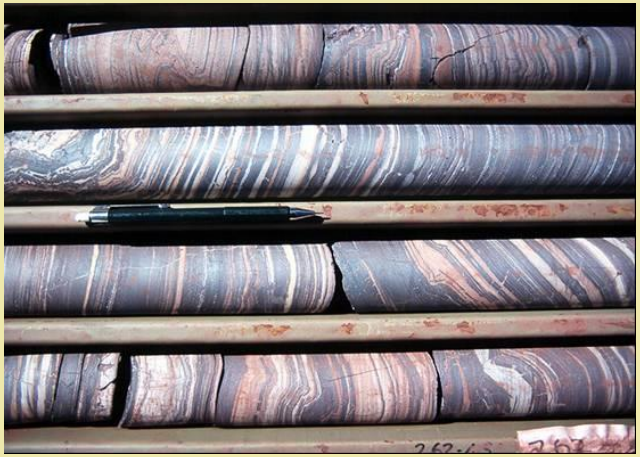




Iron Ore Properties

- What is Morphology?
- “Characteristics, configuration and evolution of rocks”
- “Origin, formation and mineral composition”

Structure



Weathering

Mineral Content

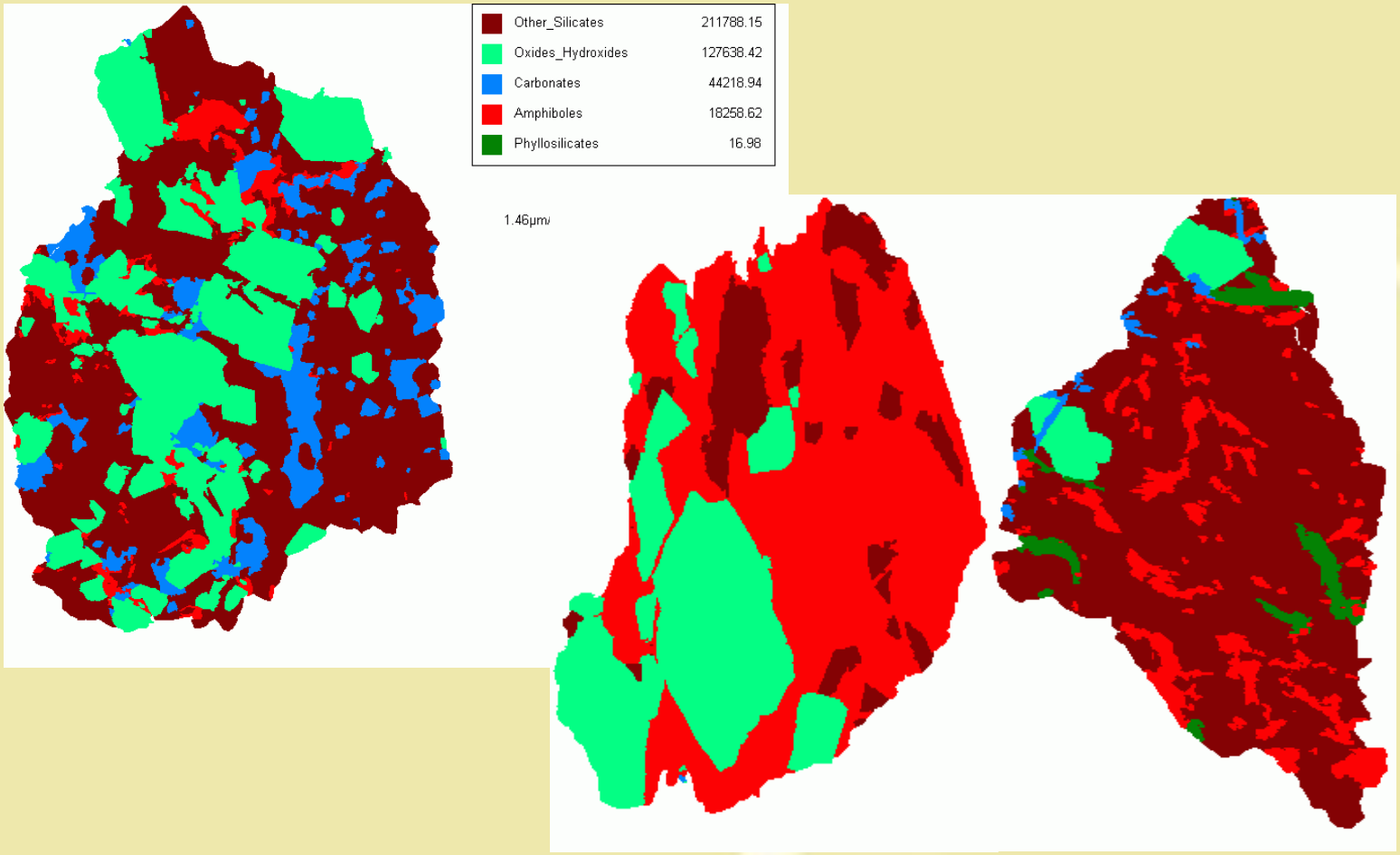
magnetite

hematite

limonite

goethite

Micro-structure



Relationships?

- Do any of these relate to grinding circuit design?

Relationships?

- Yes and No

Relationships?

- Yes
  - they all contribute in some way

But

- No
  - not in any universal way related to morphology
  - there are other factors
  - Often several comminution routes are equally technically viable

However

- There are some general rules
  - So what are the drivers?

DRIVERS

Grade: high and low grade have different processes

Grain size: affects number of size reduction stages

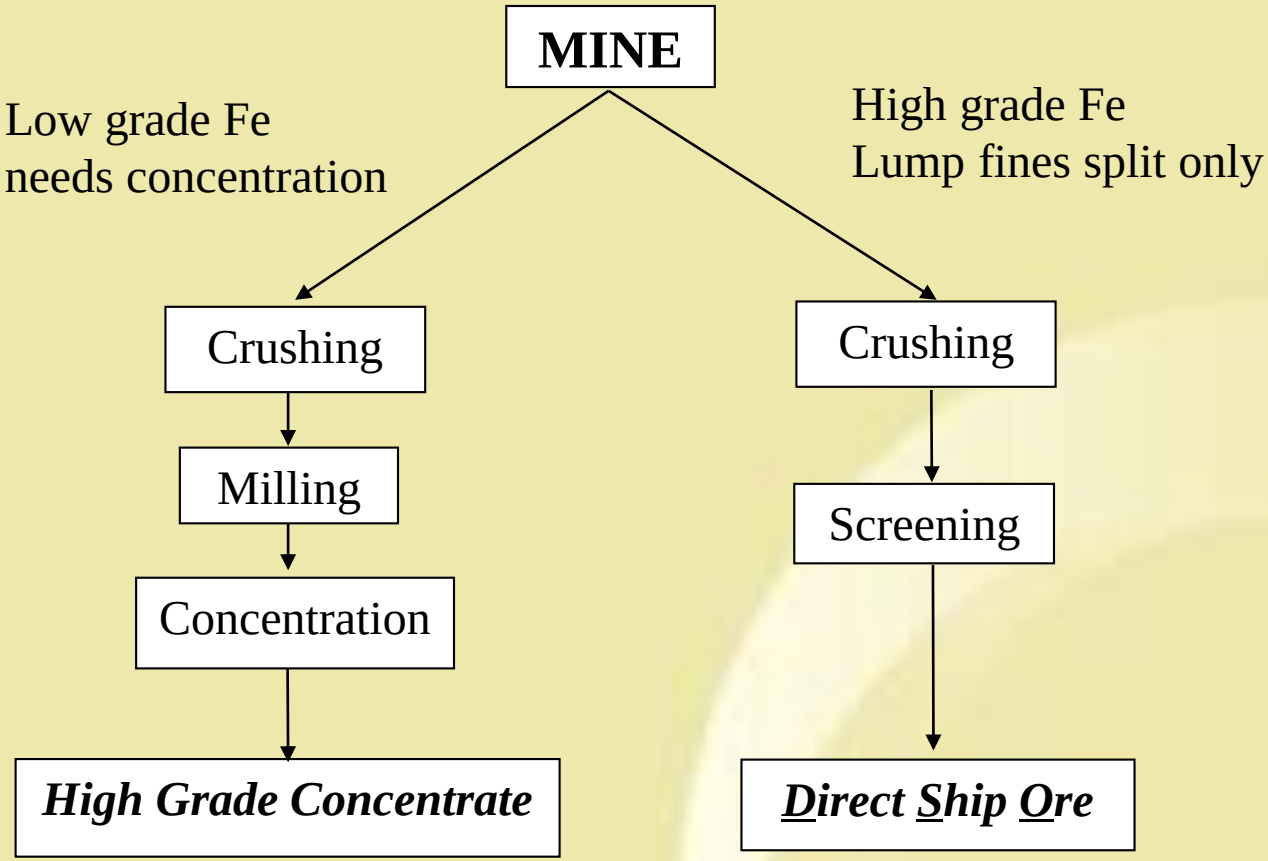
Hardness: affects size and type of equipment

Hardness variability: affects type of equipment

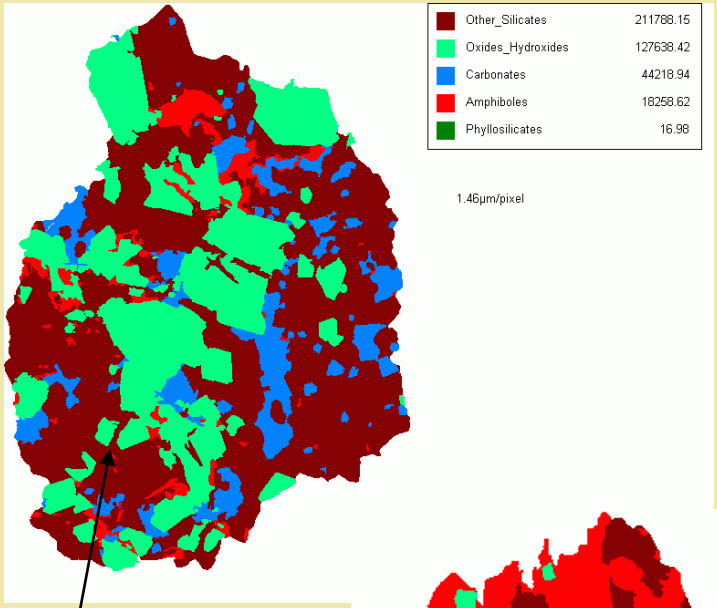
Capex/Opex: dictates final choice between suitable designs

Local preference (prejudice): may overrule all others

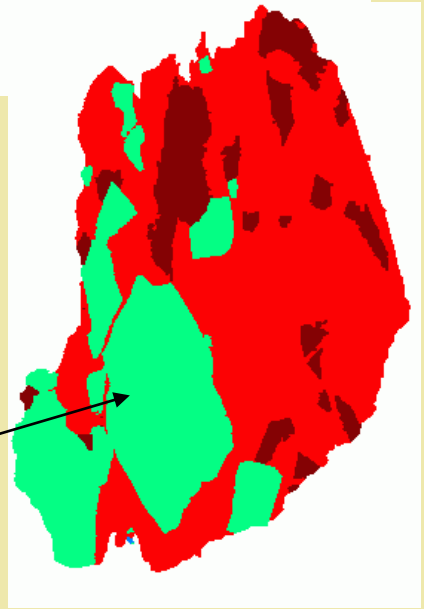
GRADE


MINE
Low grade Fe
needs concentration
High grade Fe
Lump fines split only
Crushing
Milling
Concentration
High Grade Concentrate
Crushing
Screening
Direct Ship Ore

GRAIN SIZE



Finer grained



Coarser grained

To be able to concentrate low grade ore need to grind to liberate Fe oxides

The smaller the grain size of Fe oxides the finer the grind

The fineness of the grind influences circuit design, eg more stages

HARDNESS

- Influences circuit design and equipment size
- Need a relevant hardness measurement
  - Bond work index: crushing, rod, ball; UCS; IS_{50}; SPI®; JK drop-weight; SMC Test ®
- Must have proven correlation with comminution equipment performance
- Need big data base for benchmarking
- Must be easy to do, eg should be able to use small diameter drill core

SMC Test®

Drill Core Samples

PQ, HQ, NQ

Break in laboratory device:

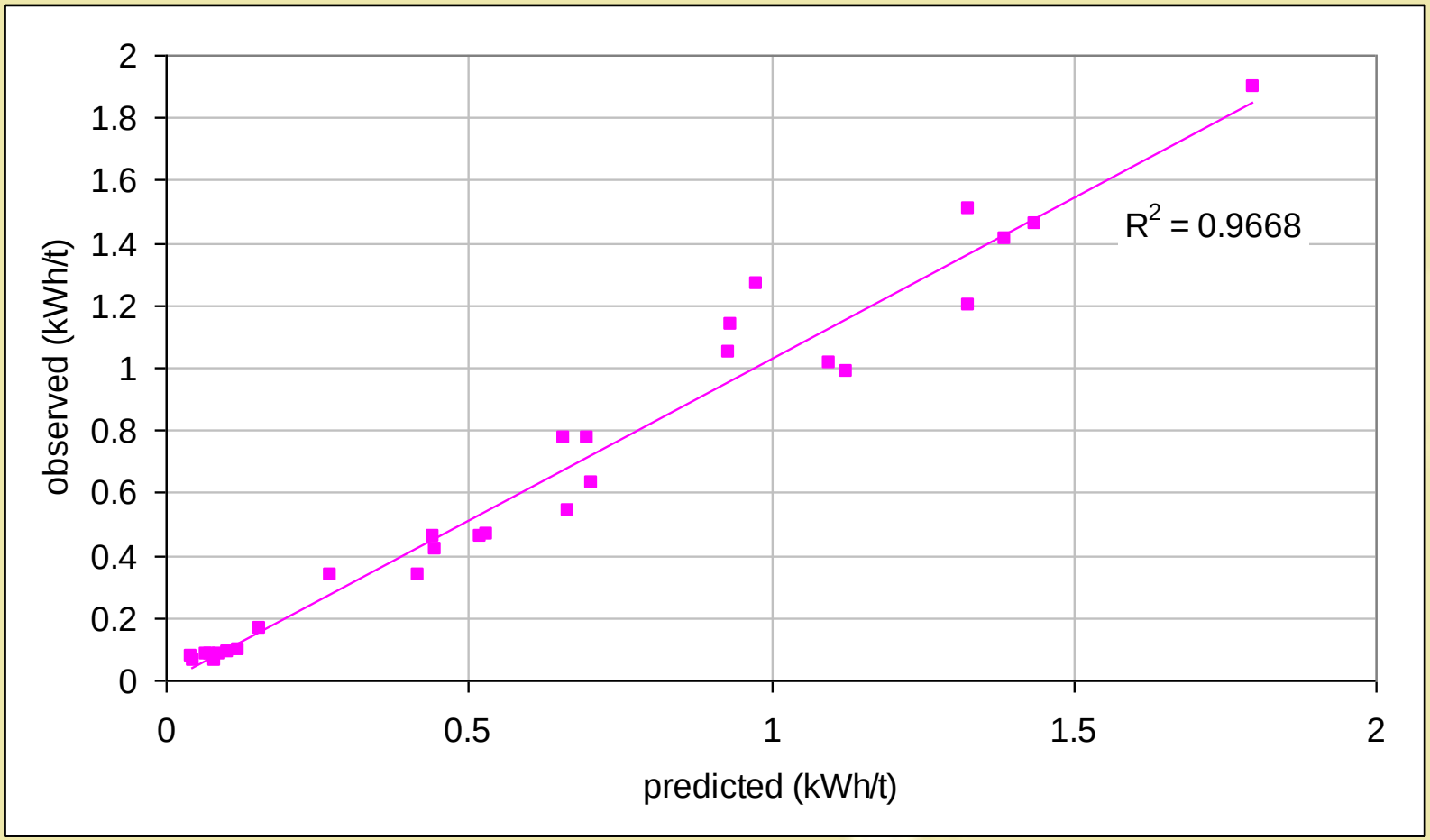
16 laboratories worldwide

Hardness Parameter

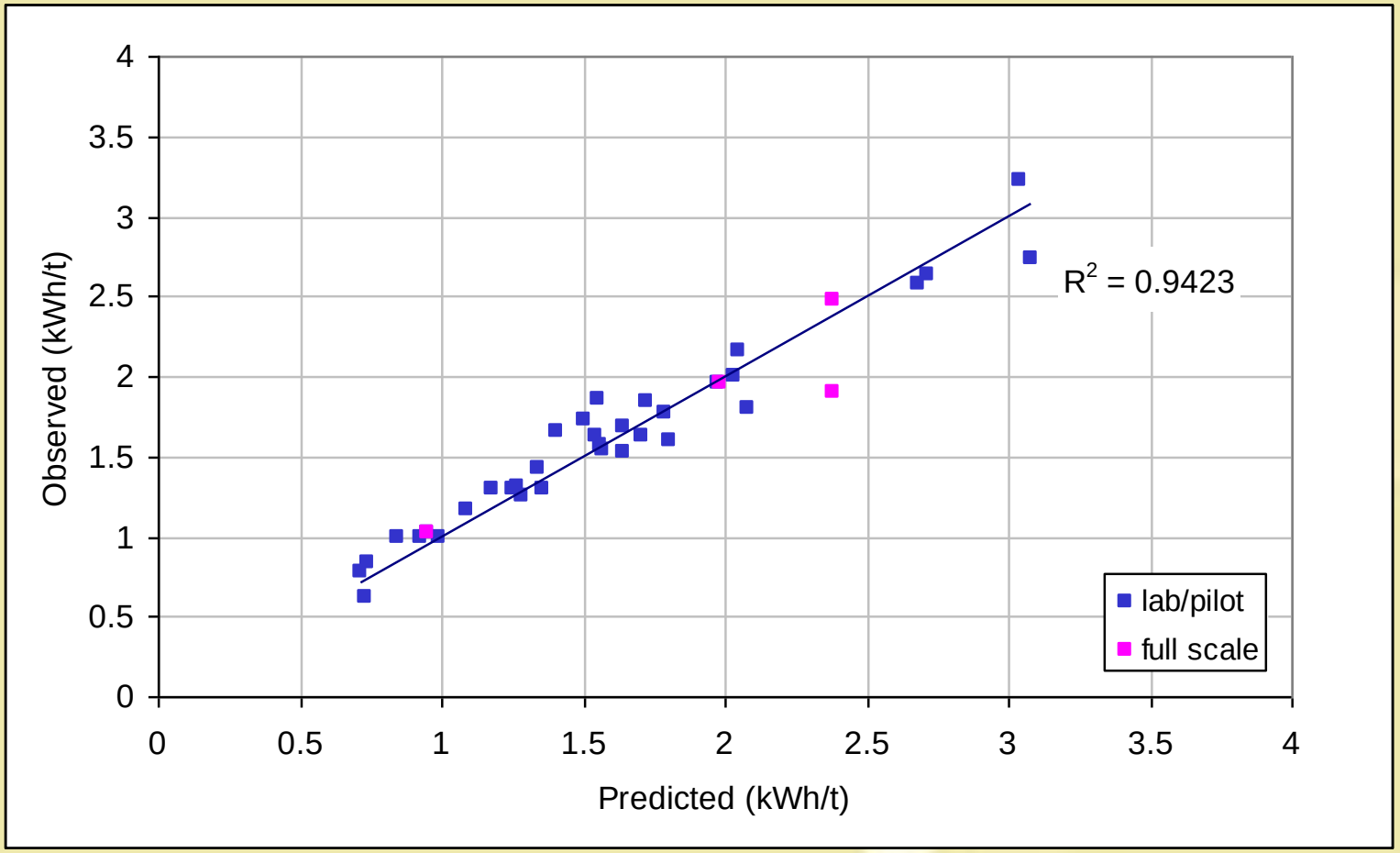
DWi

Predict AG/SAG/Crusher/HPGR

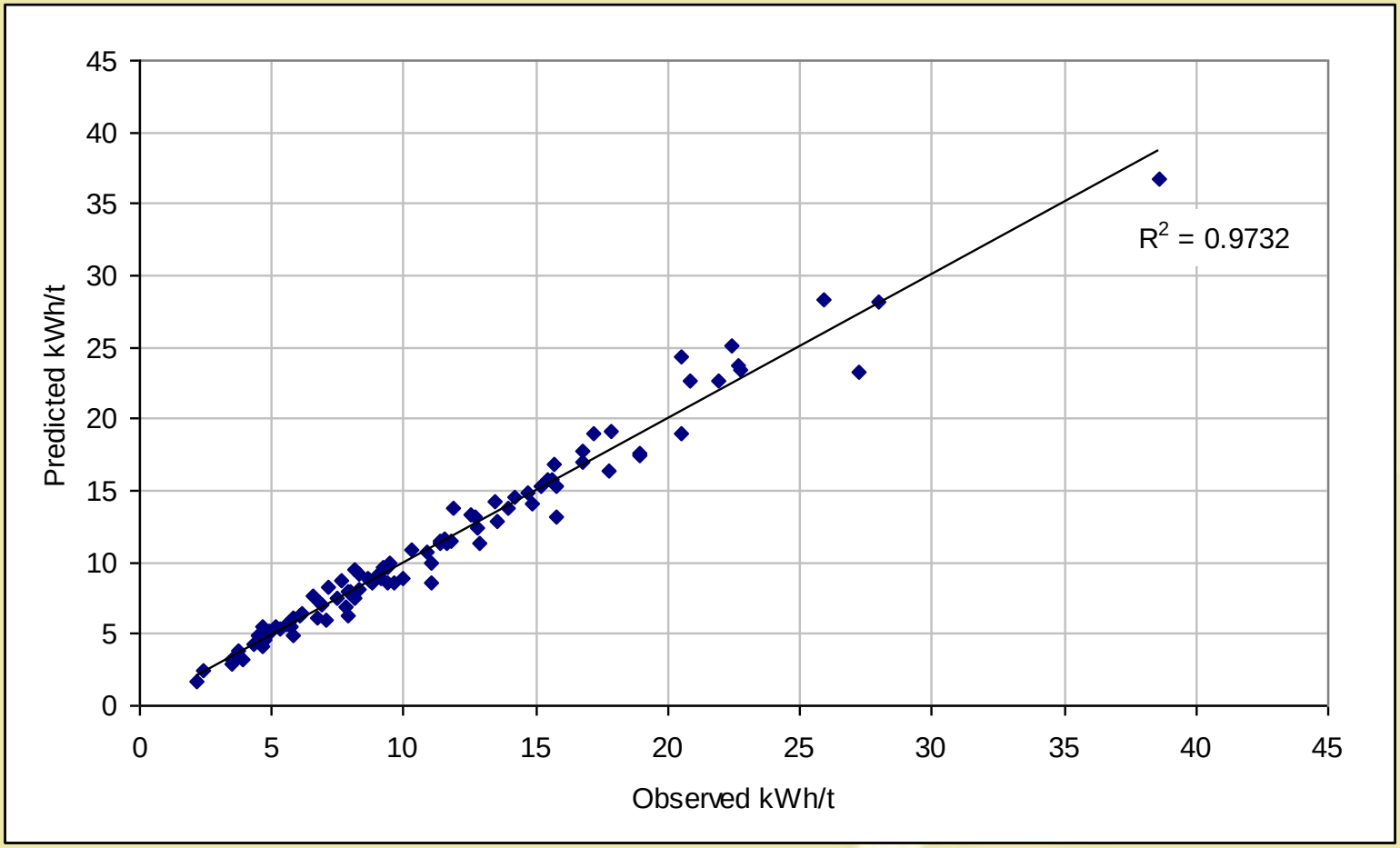
DWi RELEVANCE - Crushers



DWi RELEVANCE - HPGRs



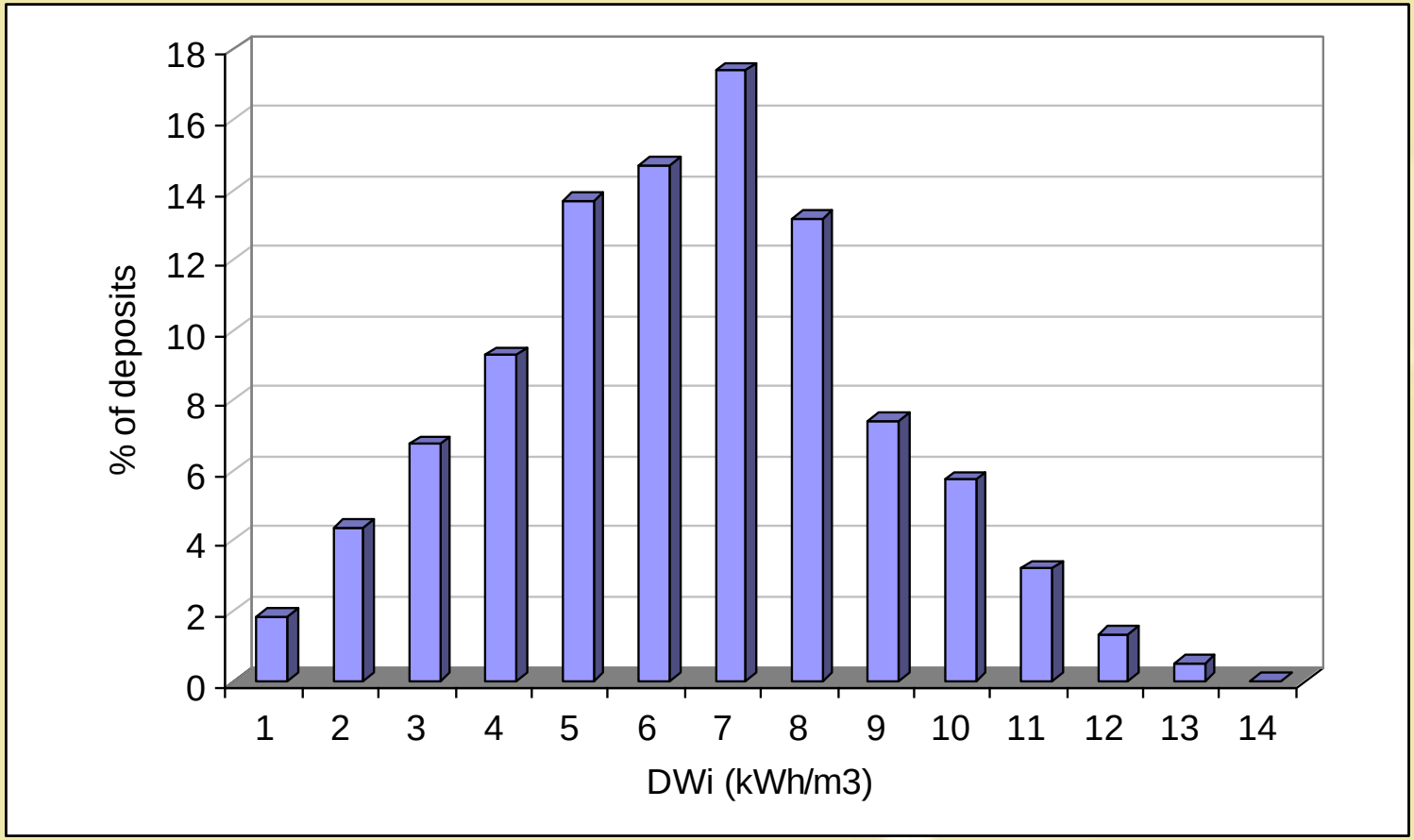
DWi RELEVANCE - AG/SAG



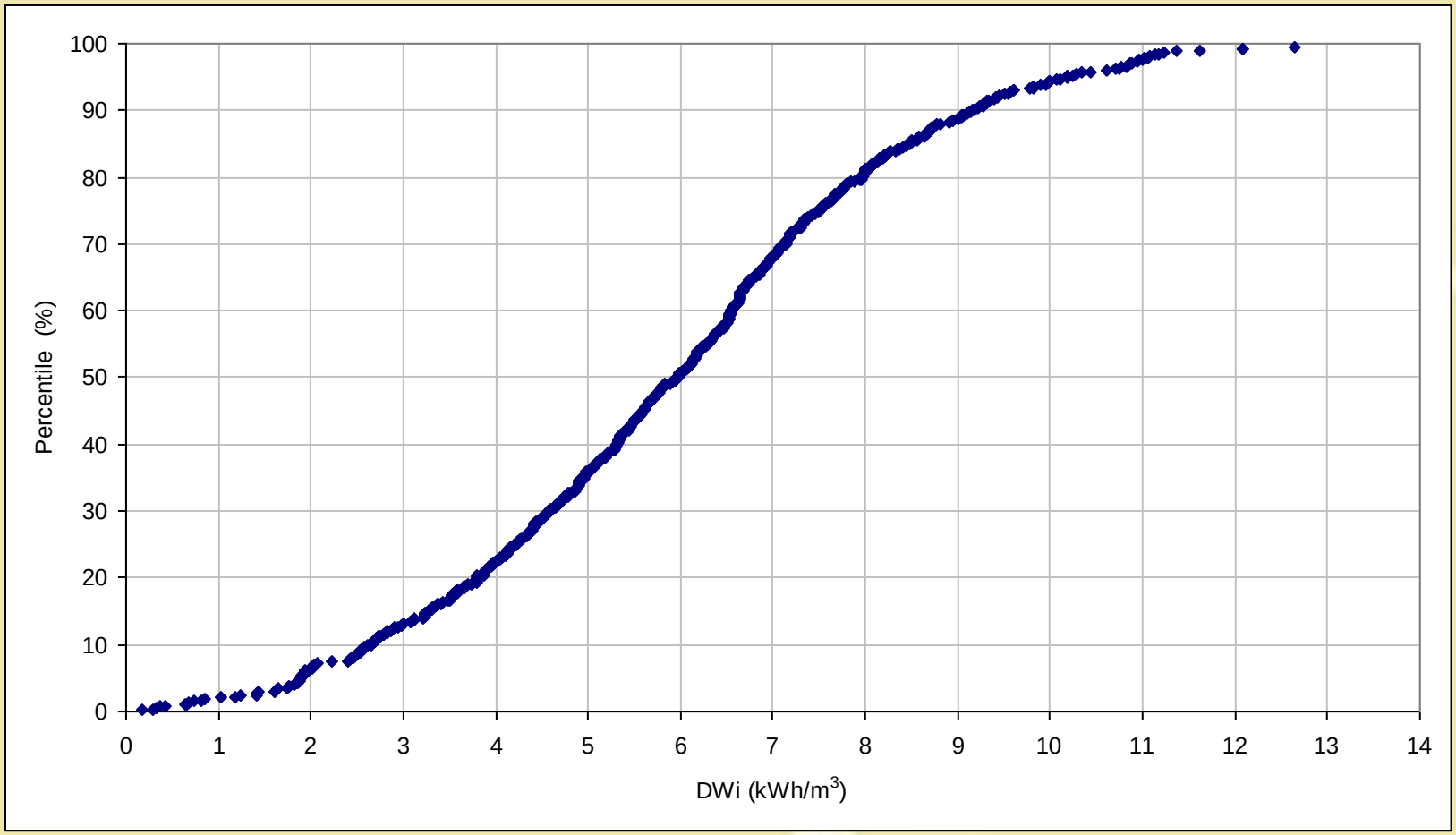
DWi DATA BASE

Over 17000 tests done to date

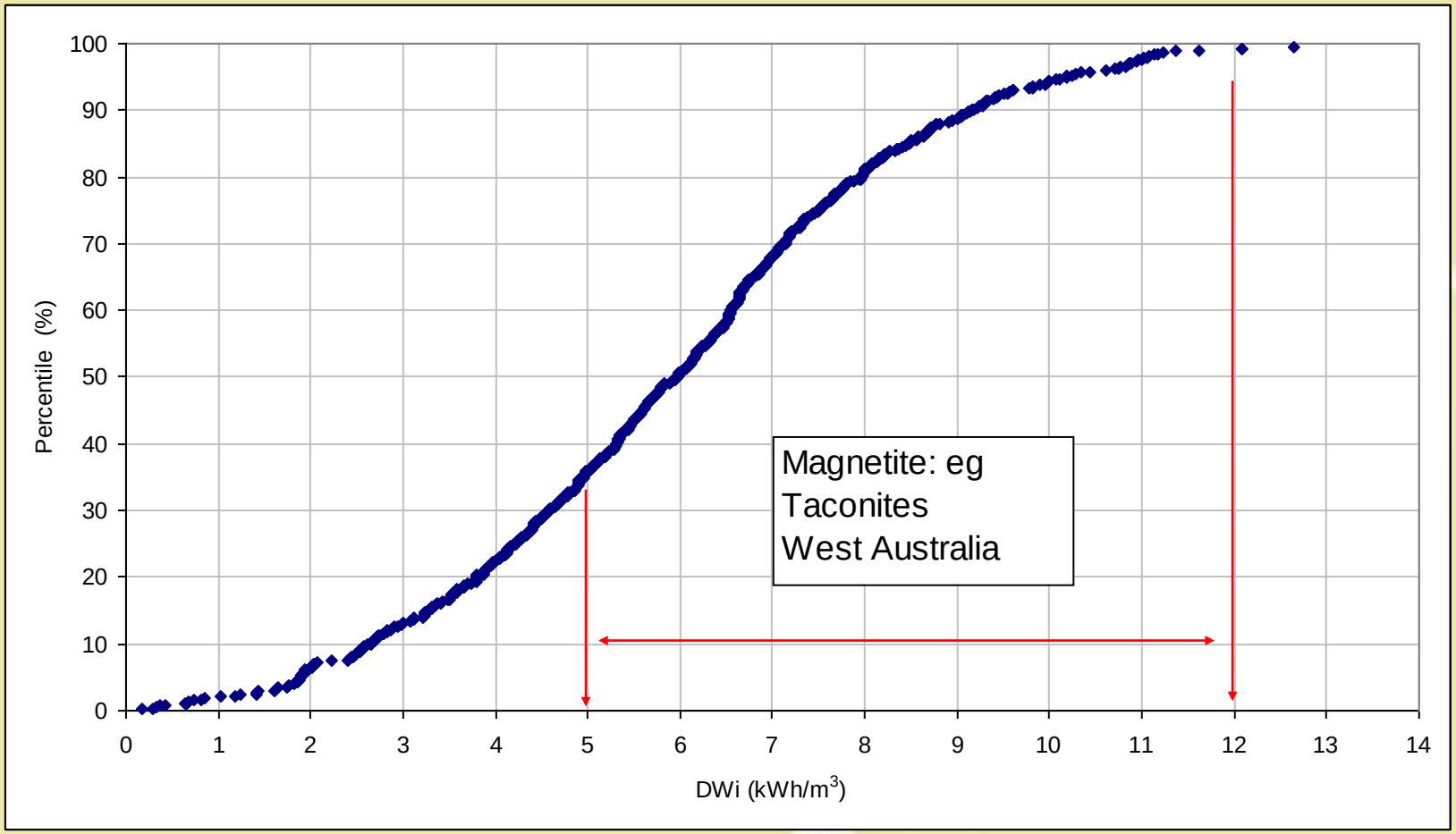
Over 700 different ore deposits



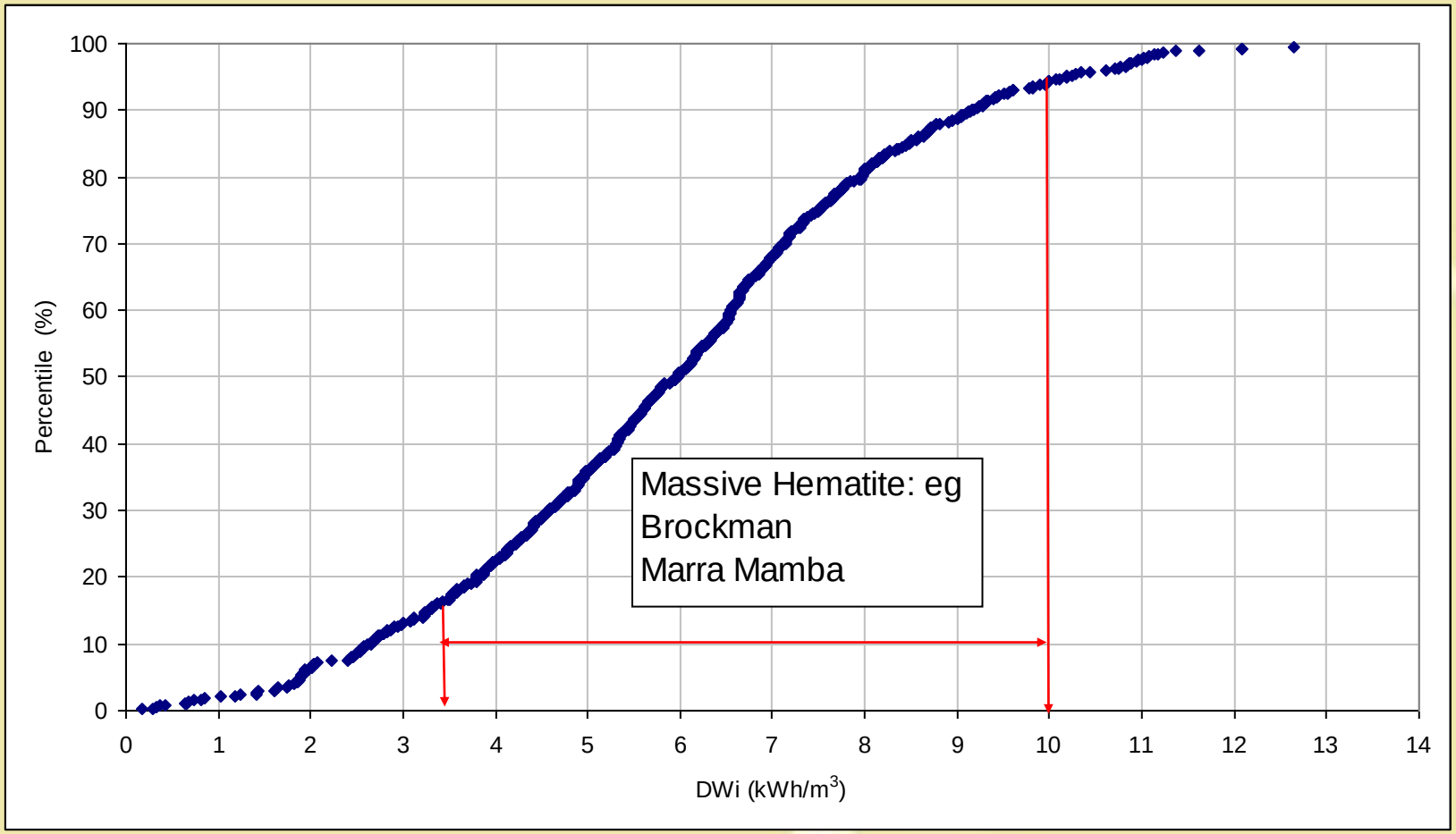
DWi Distribution



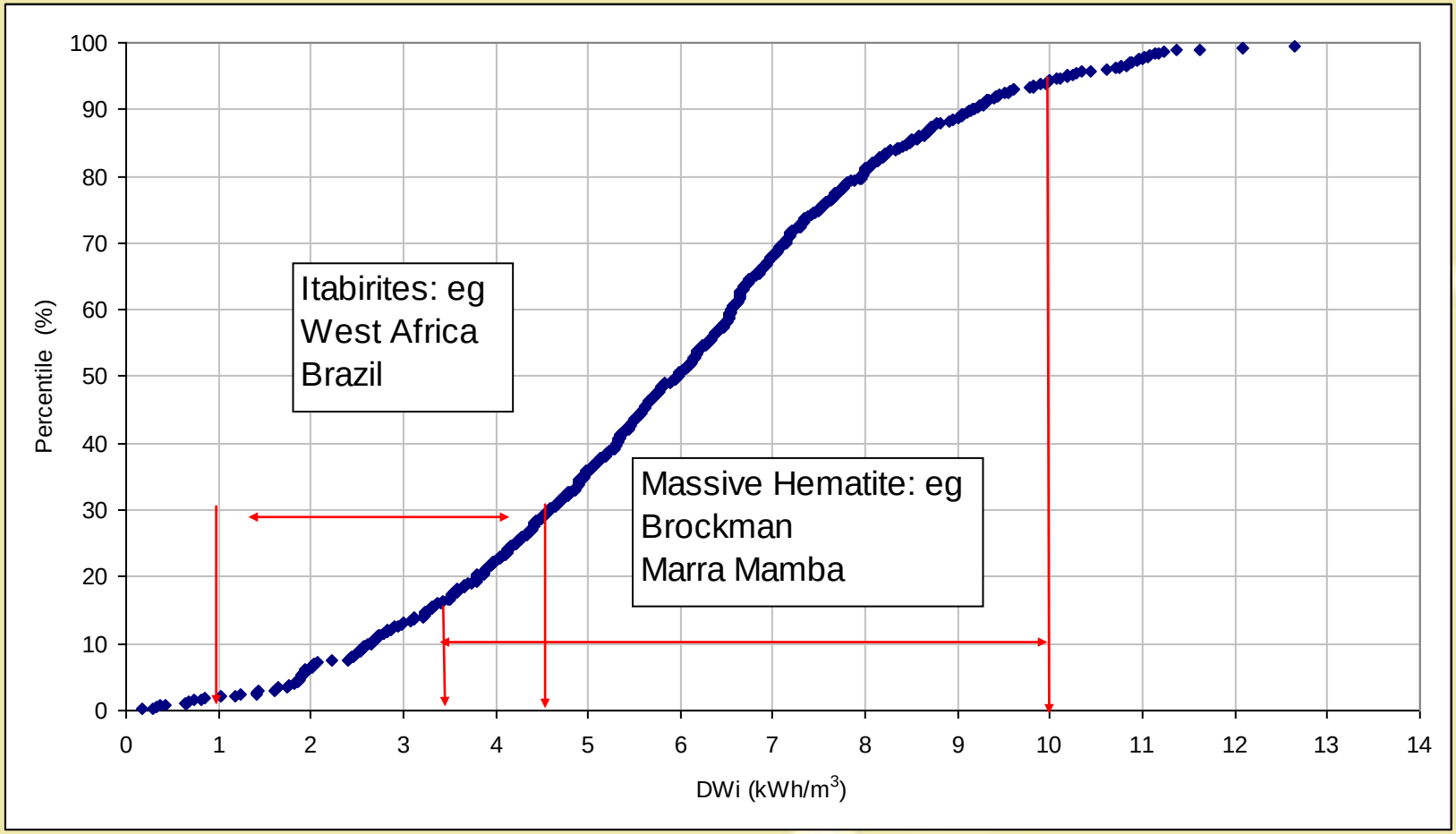
Magnetites (low grade)



Hematites (high grade)



Hematites (low and high grades)



Comminution Circuit Designs

Blasting

- Good comminution circuit design starts with good blasting design

Blasting

Bad

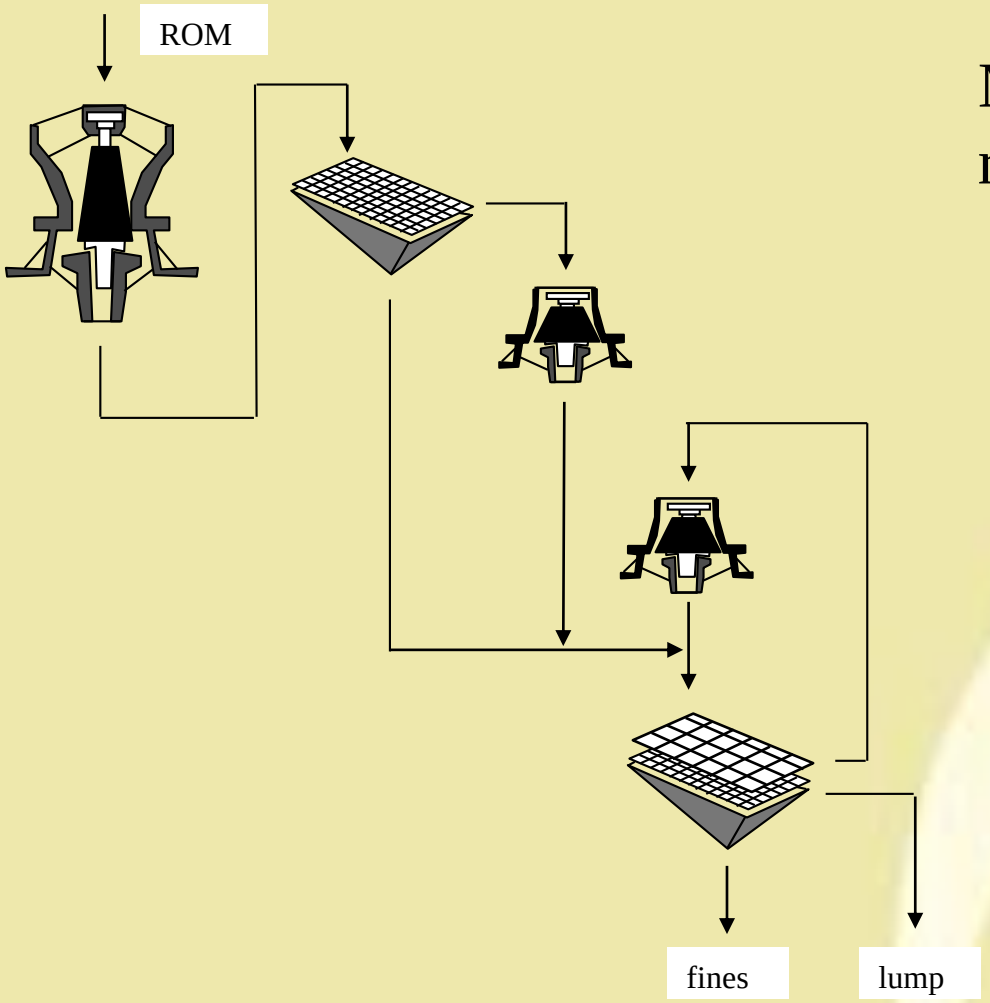
Better

BLASTING

- Needs to be tailored to process requirements eg,
  - DSO – minimise fines production
  - Fine grained magnetite – maximise fines production

HIGH GRADE CIRCUITS

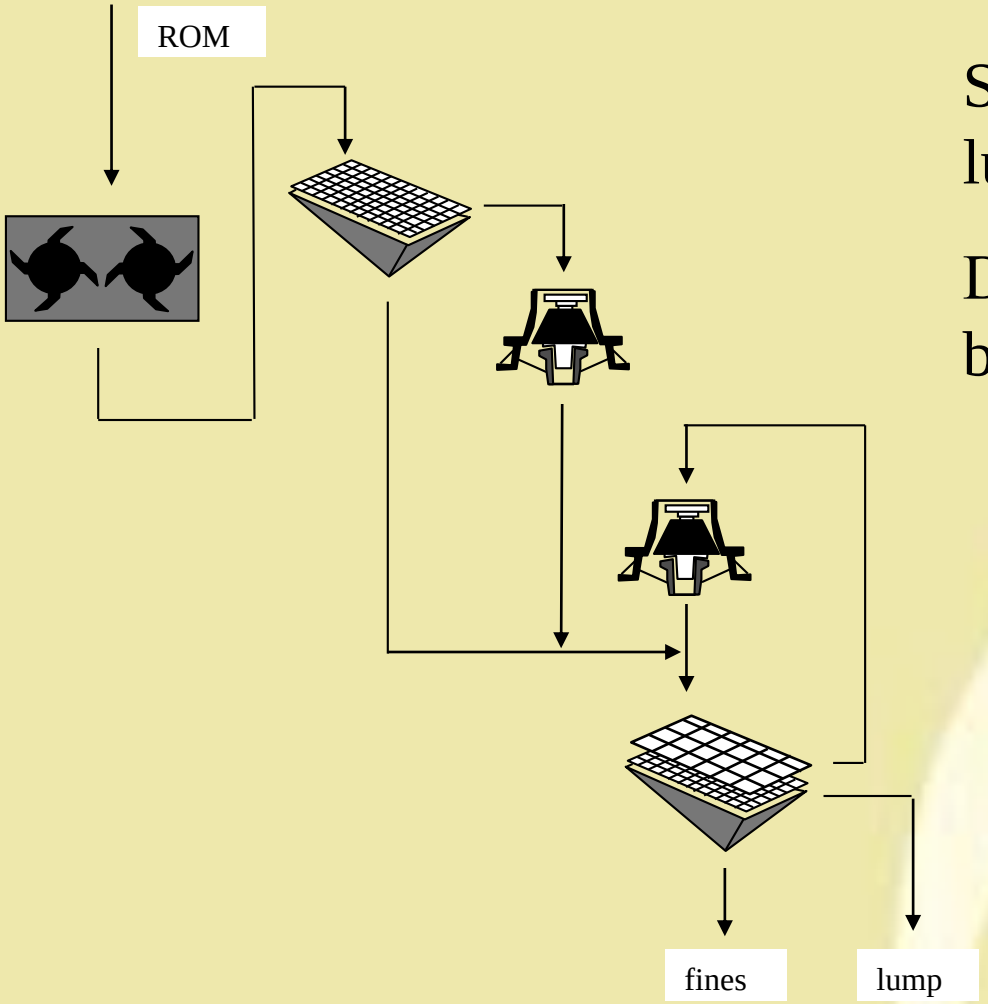
DSO Circuit



Maximise lump:fines ratio:

- Minimise amount of size reduction in a single step
- Minimise handling
- Start with highest natural lump as possible

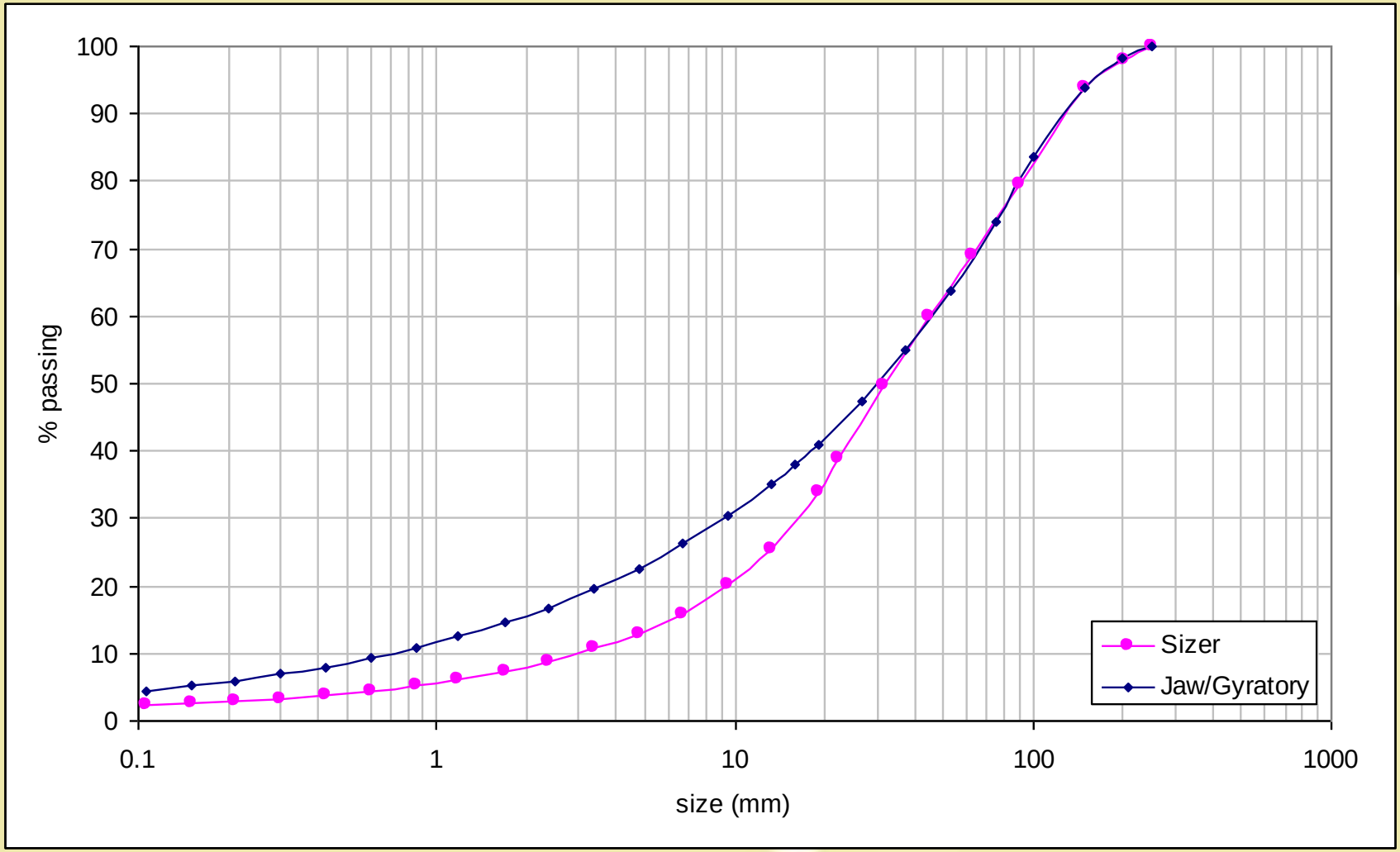
DSO Circuit



Sizers maximise natural lump

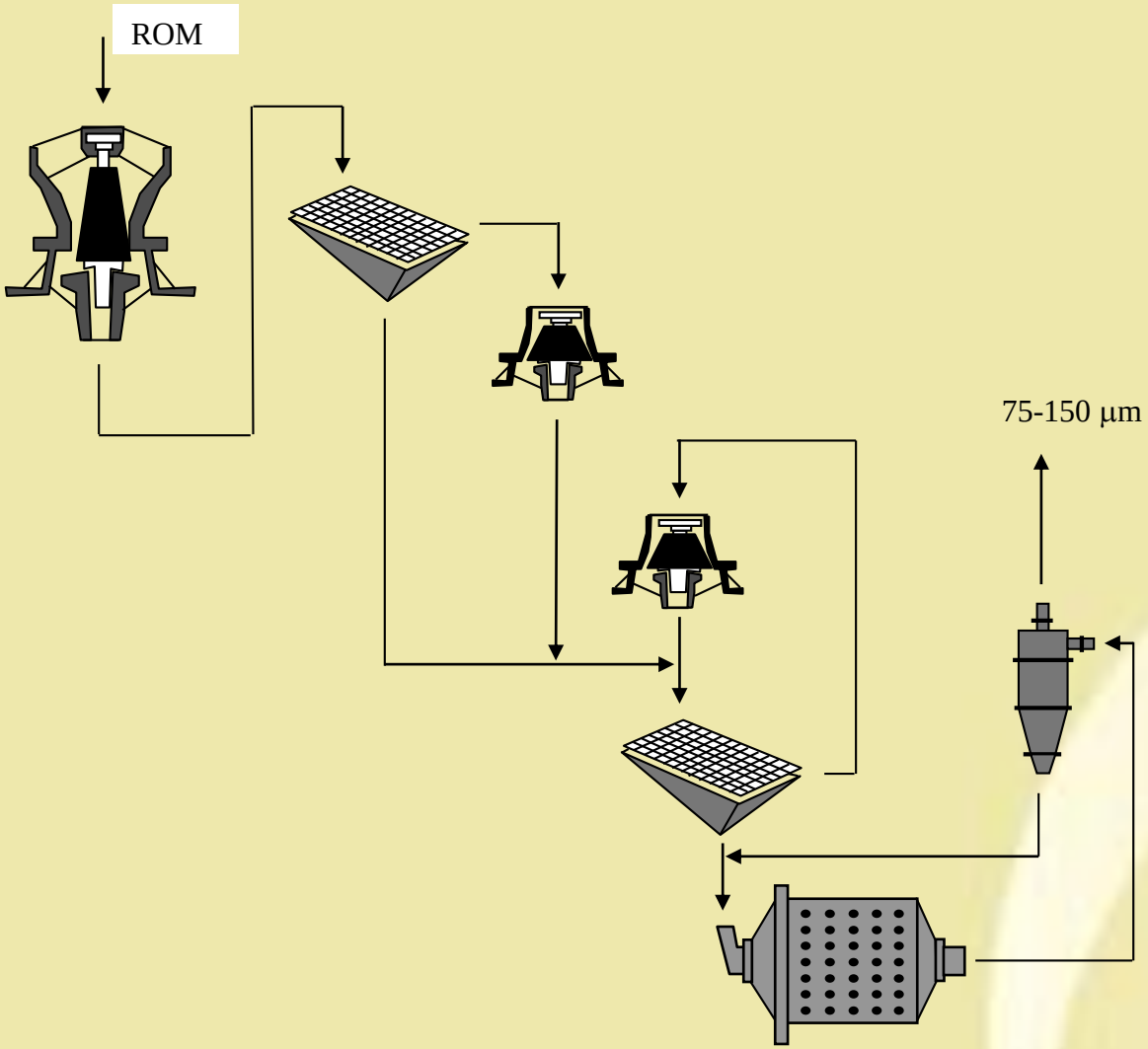
Don’t forget influence of blasting

Sizer vs Gyratory



LOW GRADE CIRCUITS

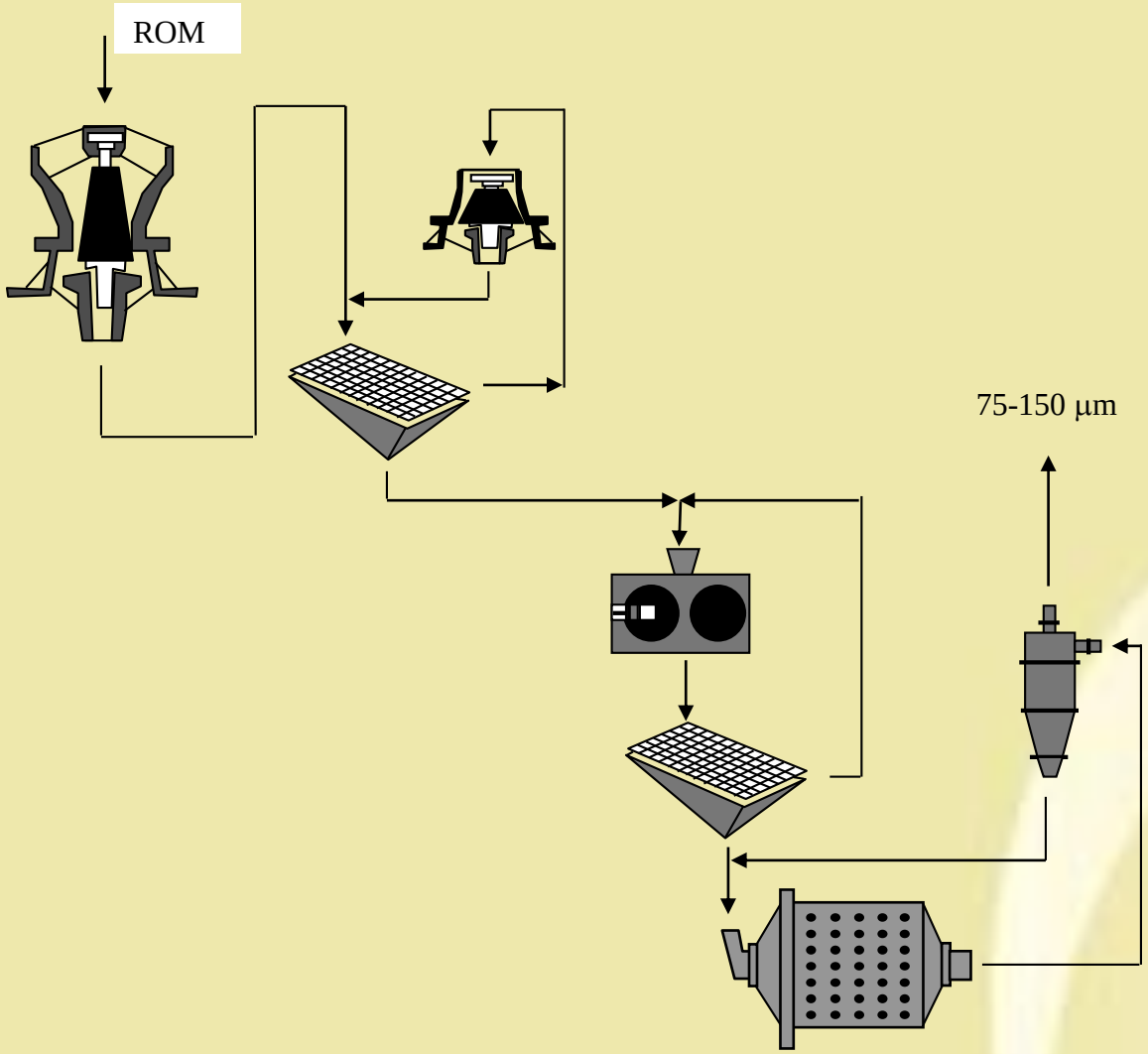
Crush-Ball



One of oldest circuits

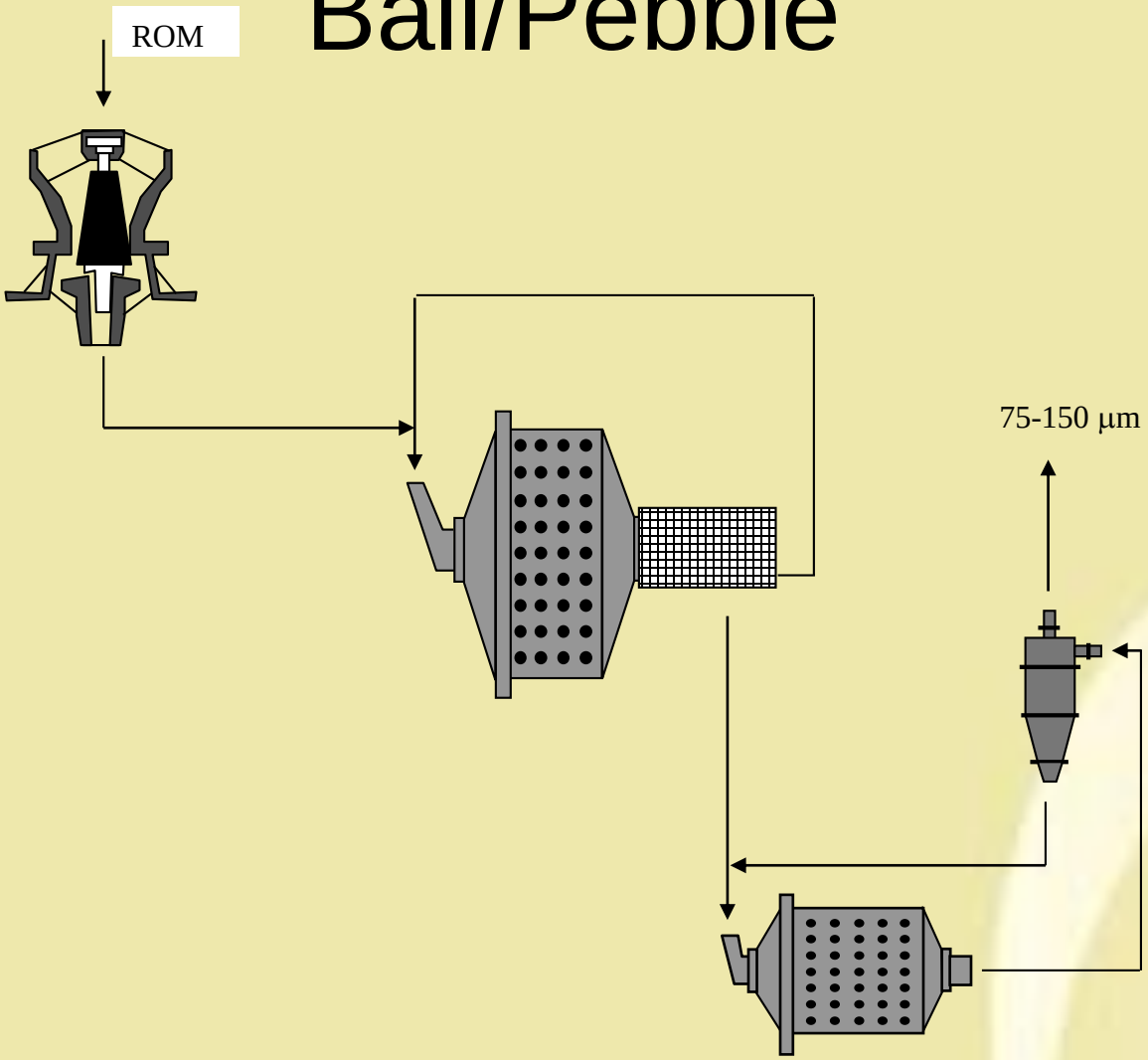
Now normally only used with very hard ores and small operations

HPGR-Ball



- Increasingly popular with harder ores
- High unit capacities of HPGRs favour large scale processing
- Energy saving advantage only seen with hard ores and coarse grind
- Good with deposits with variable hardnesses

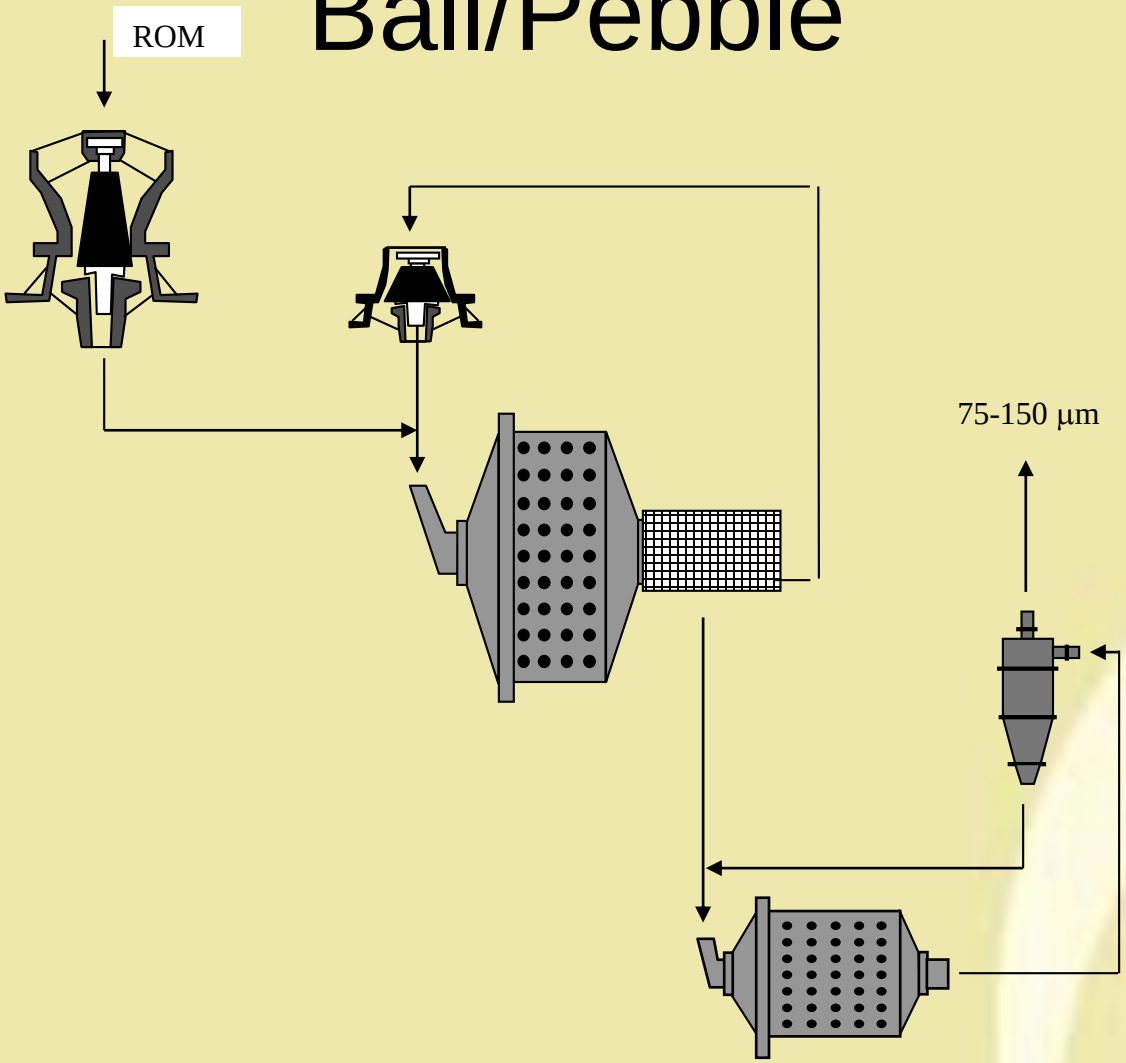
AG/SAG-Ball/Pebble



SAG circuits usually have pebble crushers for harder ores

AG circuits usually have pebble crusher

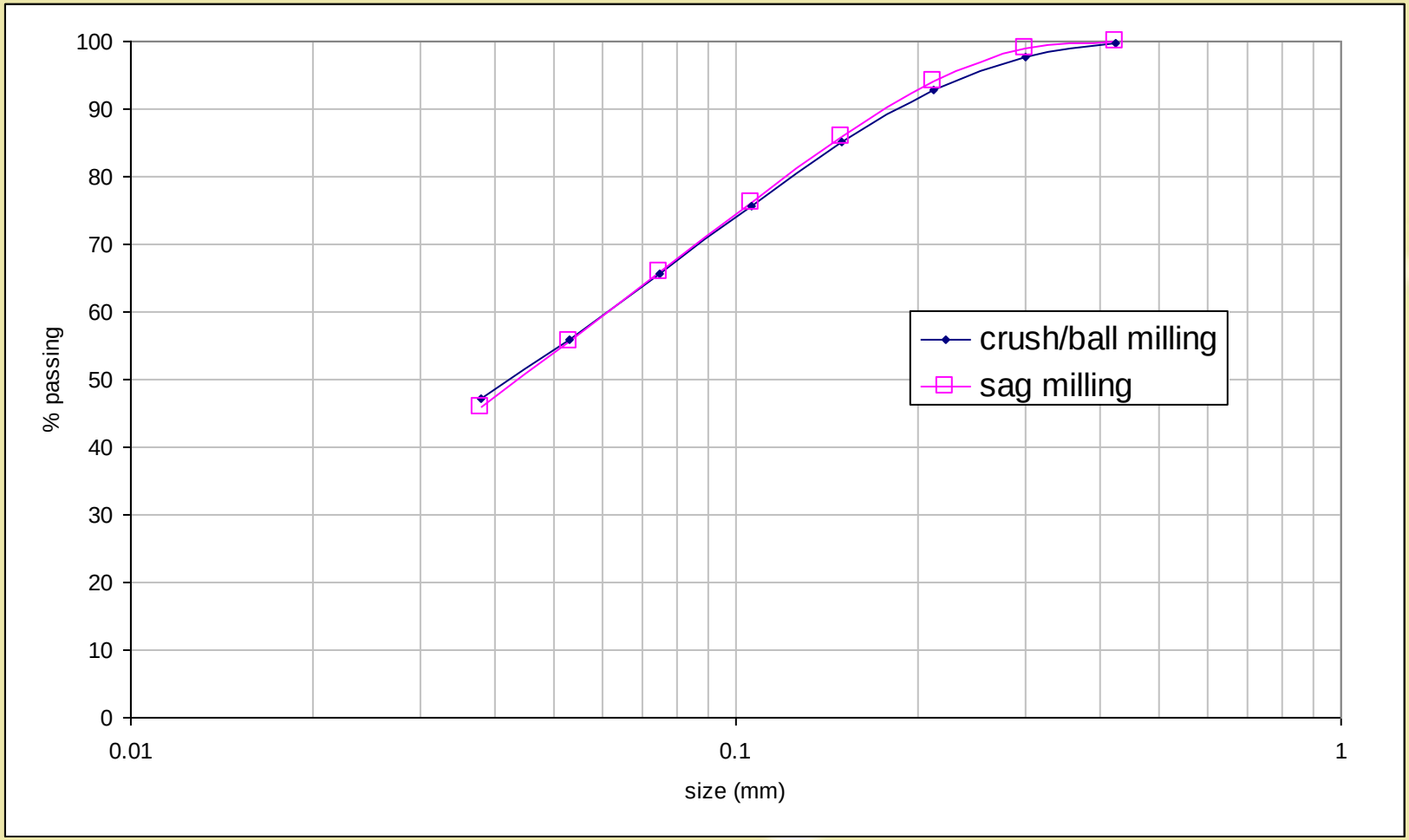
AG/SAG-Ball/Pebble



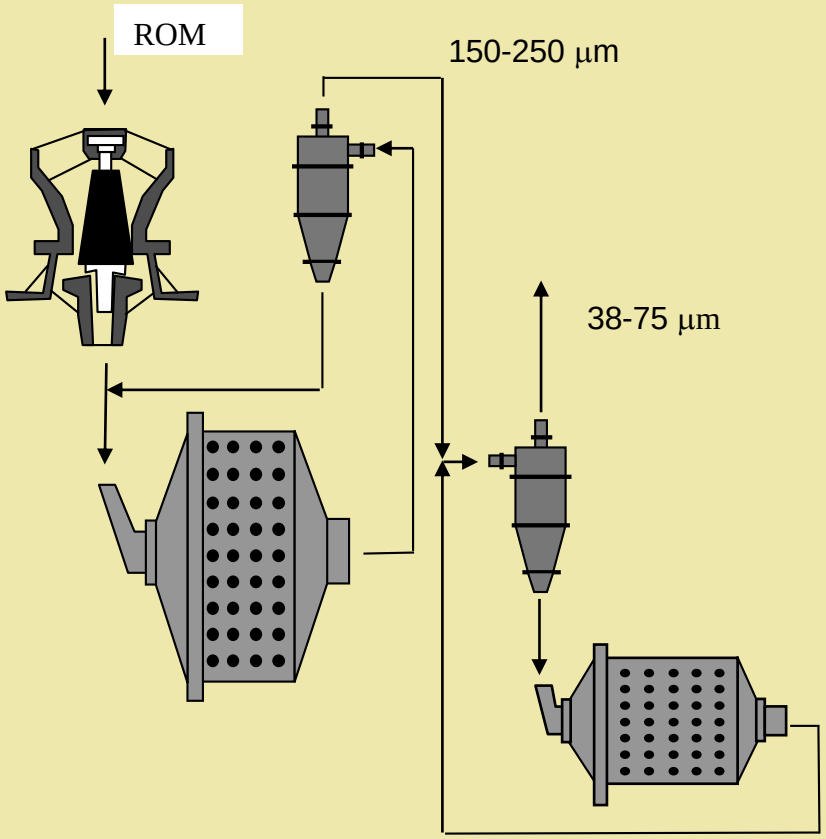
- SAG good for very high capacity
- SAG/ball particularly good for softer ores (Itabirites?)
- AG/pebble favoured for fine grinding and hard ores
- AG not good with deposits with high hardness variability
- Not good for low grade magnetite as can't concentrate after AG/SAG
- Claim by some that AG/SAG-ball gives more slime production than crush-ball.
- Evidence(?)

SLIMES

No evidence that slimes generation is any different



Closed Circuit AG/SAG



One of most common low grade magnetite circuits

Closed AG/SAG enables early gangue rejection

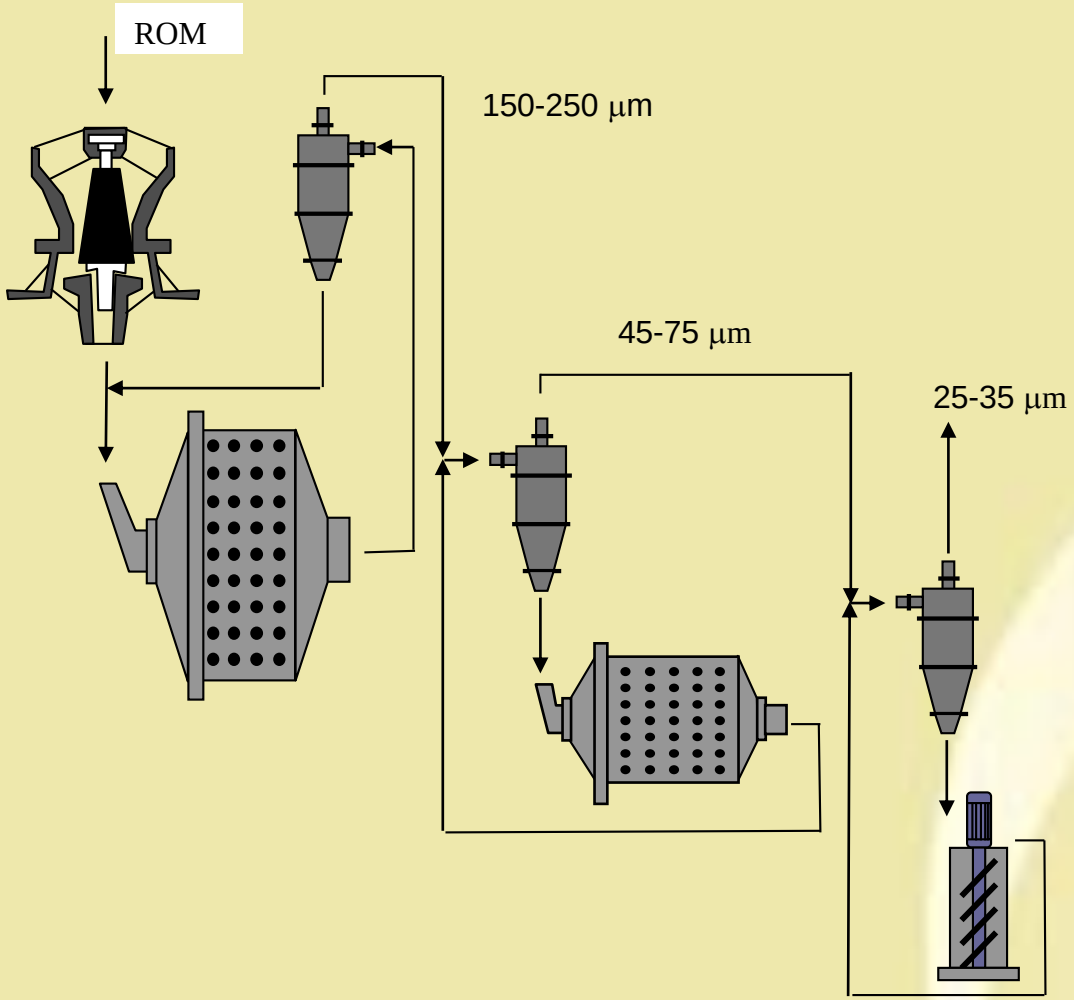
Secondary circuit able to reach relatively fine grinds – AG/pebble can get down to 38 μm; ball mill more comfortable at 75 μm

Need harder low variability deposits for AG.

SAG/ball better for softer and more variable ores but may need extra stage for fine grind

AG/Pebble lower Opex and higher Capex compared with SAG/ball

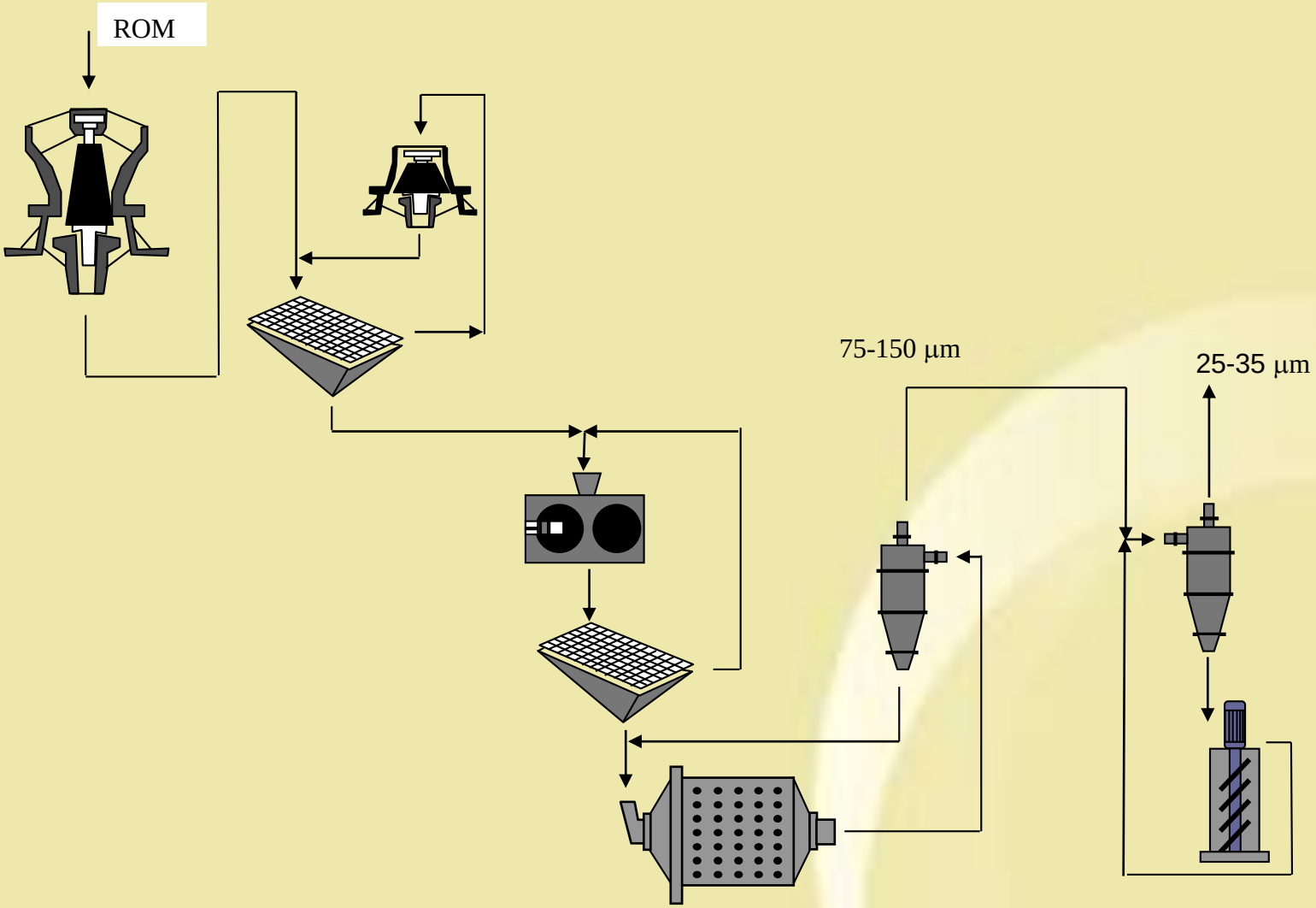
Fine grinding



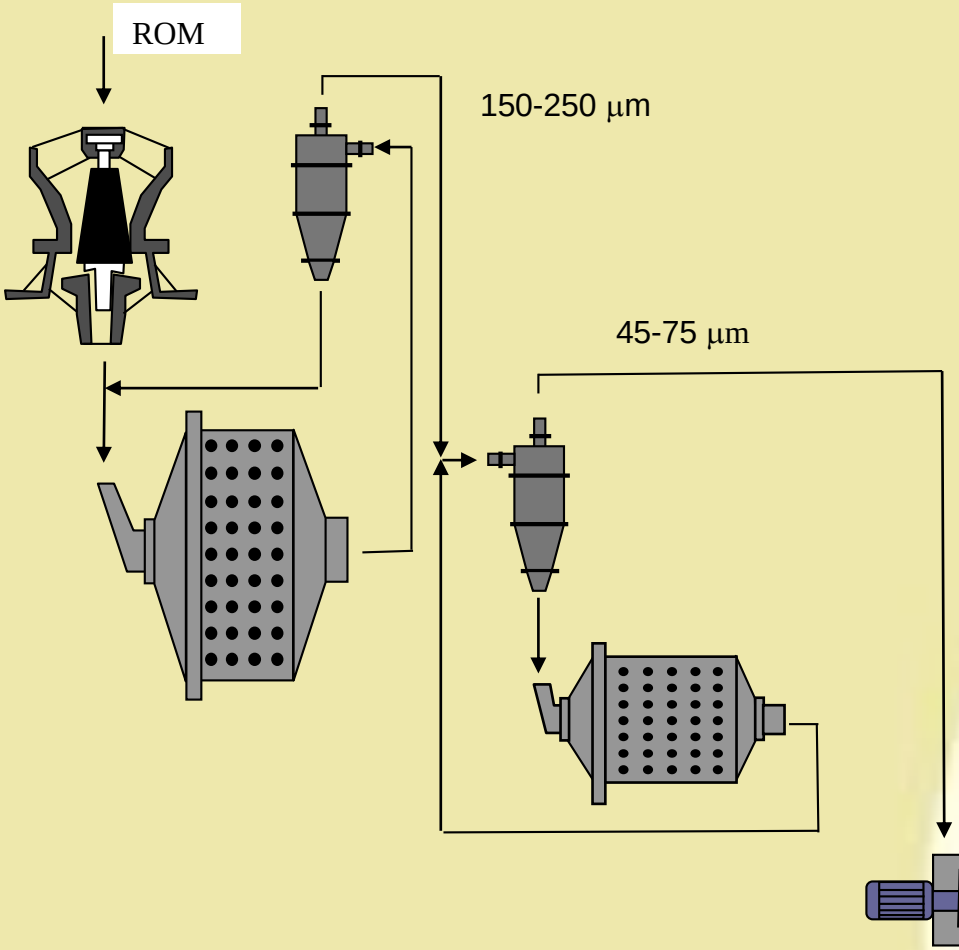
Fine grinding stage needed for some ores and/or where SAG/ball or HPGR/ball used as these generally find it hard to reach very fine grinds efficiently

Verti/tower mill

Fine grinding



Fine grinding

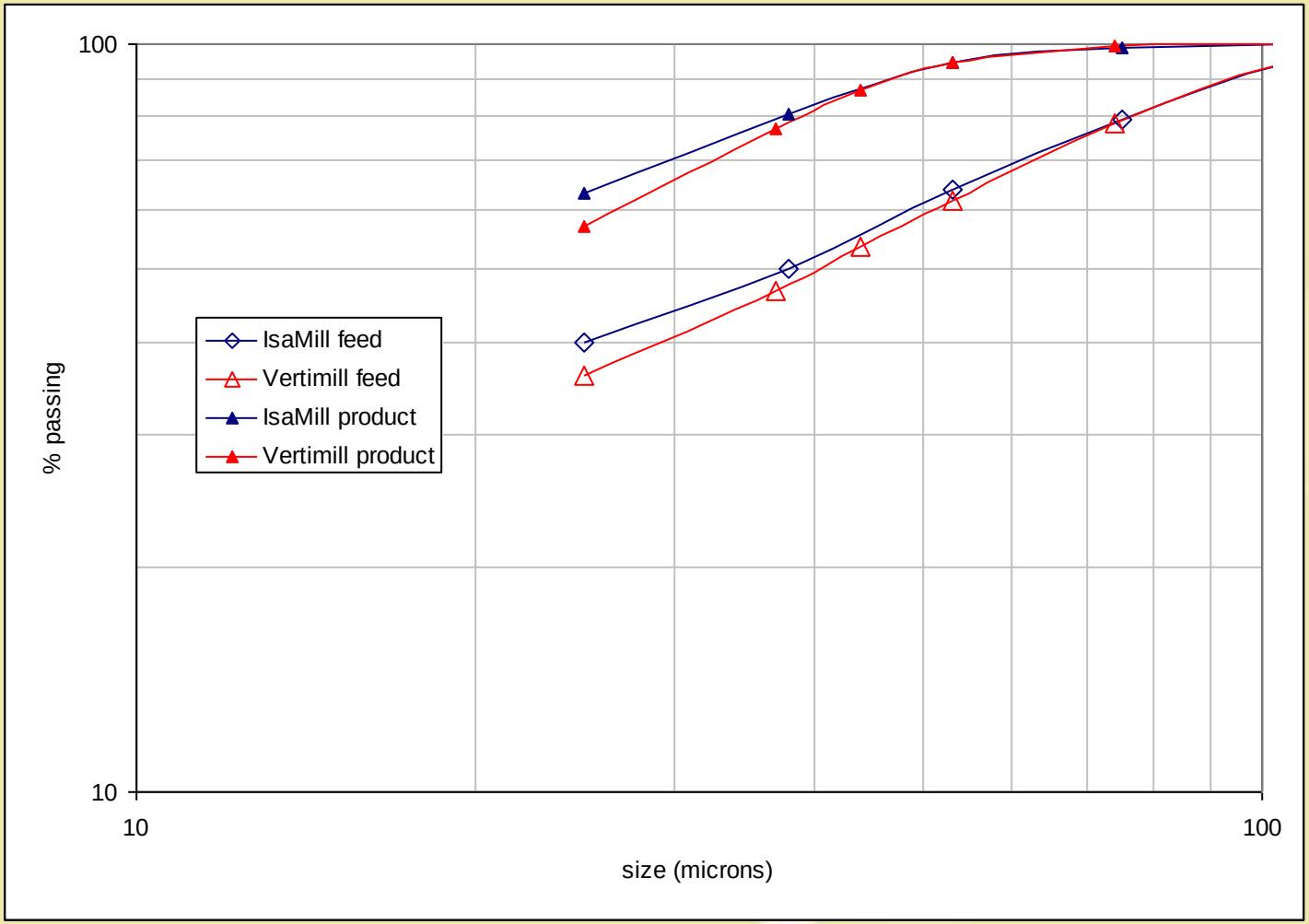


IsaMill claim no need for classification due to internal classifier

Much debate on whether IsaMill or Vertimill is more efficient

IsaMill claim that product size can be sharper ie less slimes

IsaMill vs Vertimill



Capex/Opex

	rock media	steel media
	$/t	$/t
OPEX		
Grinding media&liners	0.5	1.8
Power	3.8	3.5
Carbon tax	0.7	0.6
Other	1.8	1.9
Total	6.8	7.8
Index	**0.87**	**1.0**

CAPEX		
Index	**1.1**	**1.0**

Conclusions

- High grade – crush, screen only
- Low grade
  - Needs concentration therefore need milling
  - Finer grain size needs more stages
  - Autogenous/pebble milling better for finer grinding and harder, uniform ores
  - SAG/ball milling better for softer more variable ores and less fine grinding; Vertimill/IsaMill stage may be needed for finer grinding
  - HPGR/ball good for harder more variable ores;Vertimill/IsaMill stage may be needed for finer grinding
  - Often several circuits technically suitable for a given ore so Capex/Opex to decide
  - Autogenous routes lower on OPEX and higher on CAPEX