Tuning the Feed to the Primary Crusher

Lawrence J. Mirabelli – Senior Technical Consultant

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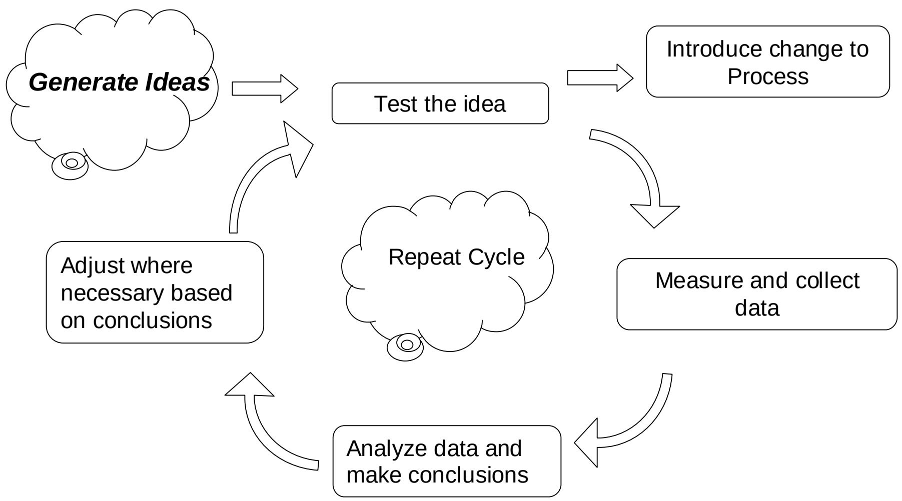
Tuning the Primary Crusher Feed

- **Blasting is only one part of the Business Improvement Process**



Continuous Improvement makes successful change!

- **Business Improvement Culture**
  - ✓ **Proactive**
  - ✓ **"Do it right today."**
  - ✓ **"Do it better tomorrow." and …….**
  - ✓ **"Whatever you do. Track metrics and pay attention to details."**
  - ✓ **Focus on the overall process**
  - ✓ **Determine the effects on the entire process from changes to any or all parts of it.**

What we want.   vs What he have.

What we have.

What we want. vs What he have.

What the blast contributes to the crushing process.

Crushing Rock with Explosives

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Blasting - A Value Adding Process

- **Blasting is the first crushing stage and the first stage to add value to the quarry product line.**
- **The muck pile is the crushed rock that is the direct result of the drill and blast process.**
- **“Run of Quarry” (ROQ) is a general term used to describe the gradation of the crushed rock in the blast muck pile fed to the primary crusher. ROQ changes from load to load, blast to blast.**
- **That total percentage of blast muck pile that does eventually make up the ROQ is the measure of the <u>effectiveness</u> of your drill and blasting program.**
- **Normally, nearly all of the blast muck pile makes up the ROQ.**
  Or ……does it?

OR Does it?

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Measures of Efficiency in the Blasting Program

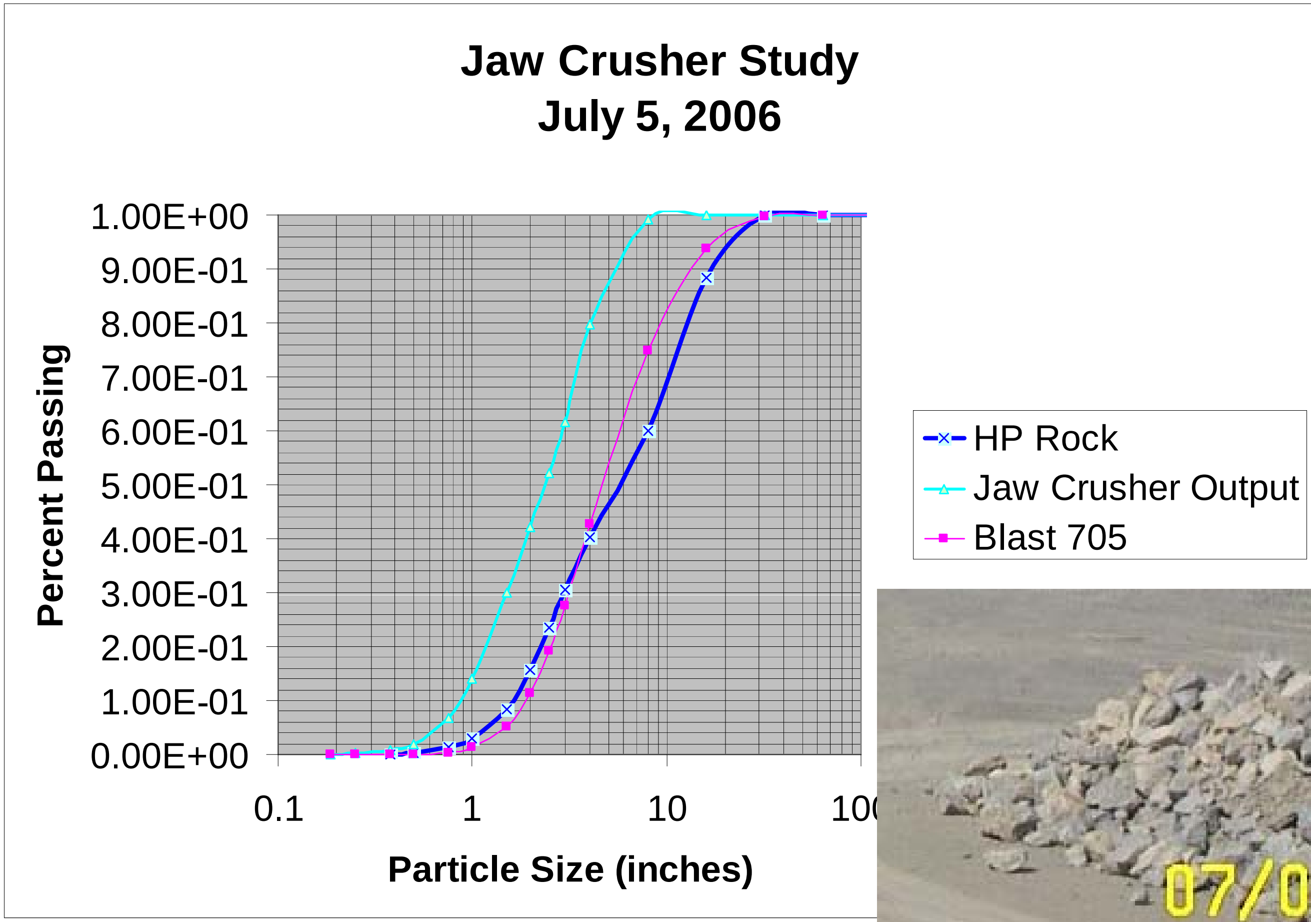
- The percentage of the blast muck pile that makes up the ROQ without incurring additional cost is a measure of the efficiency of the drill and blasting program.
- Consistency in the range of gradation making up the ROQ is another measure of the efficiency of the drill and blasting program.
- The difference between the range of gradation for the ROQ and the optimal feed gradation of the primary crusher is the last measure of the efficiency of the drill and blast program.

Oversize Rock in ROQ Reduces Value.

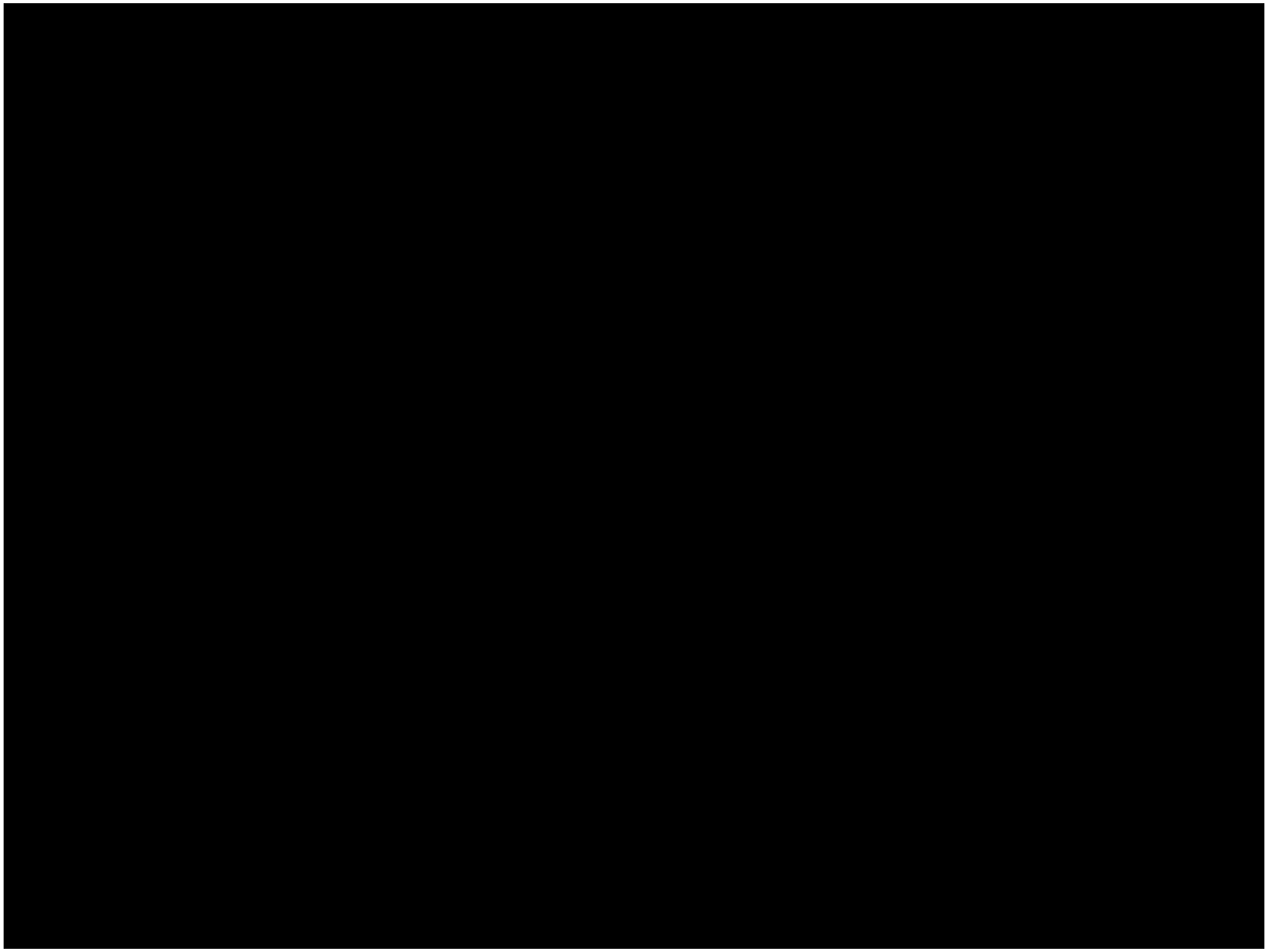
What's the real cost of oversize?

- Remember it has already been drilled and blasted once!
- It needs to be broken again (hammering) either in-place in the muck pile then loaded and hauled off to the primary crusher with the rest of the muck pile….. or
- Lifted and sorted off to the side for later handling (blast, hammer or drop ball) ……or
- Loaded, hauled and dumped out of the way for later handling (blast, hammer, drop ball)….
- Hammer, Drill and Blast, or Drop Ball.
- Lift again and hauled off to the crusher.
- Used as safety berm for ramps and benches and inventoried for future use.
- Remember "hammer" rock alone is a uniformly coarse fragmentation. It runs at a much reduced rate through the primary!

Gradation of Impact Hammer Pile..

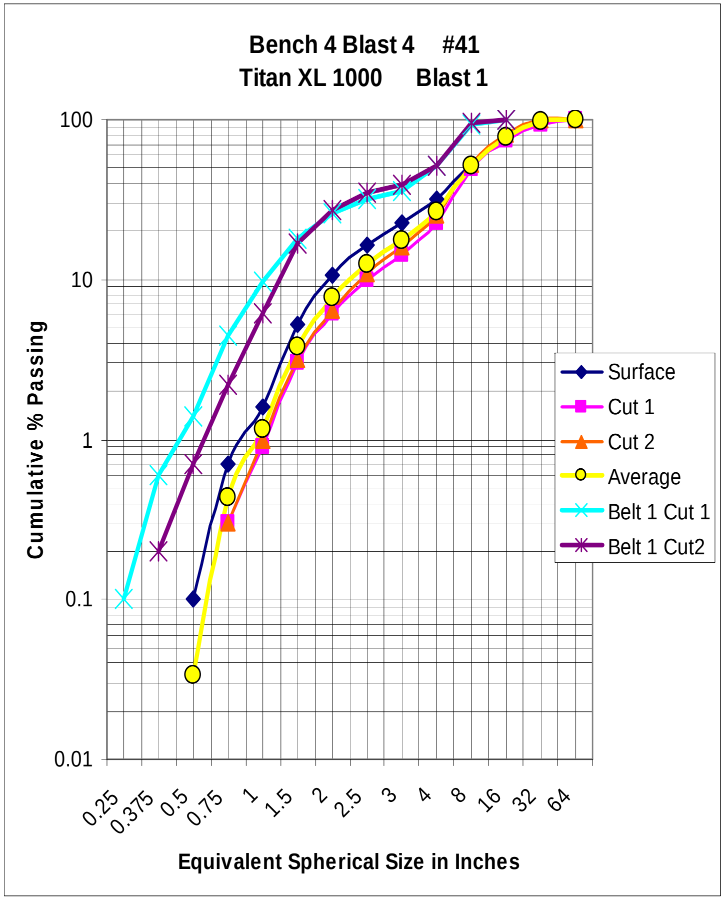


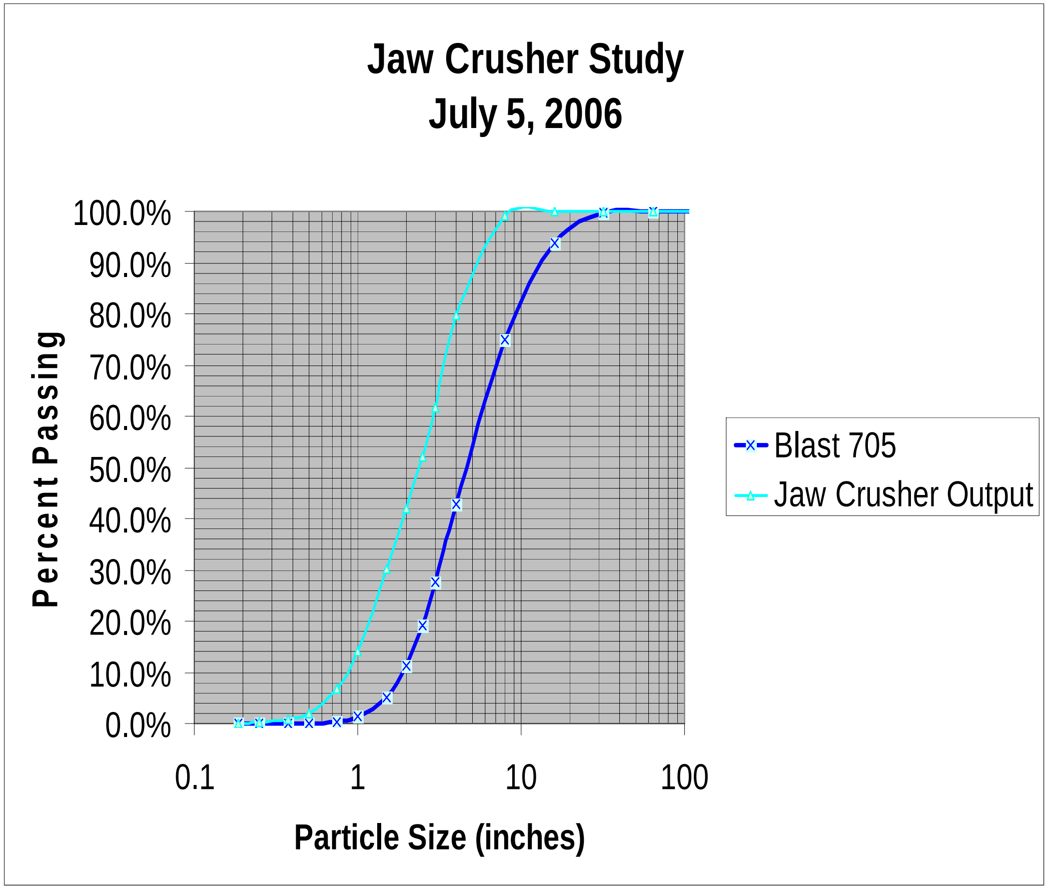
Hammer Rock at the Primary Crusher



Toe or floor grade problems reduce Value.

Examples of ROQ Gradations





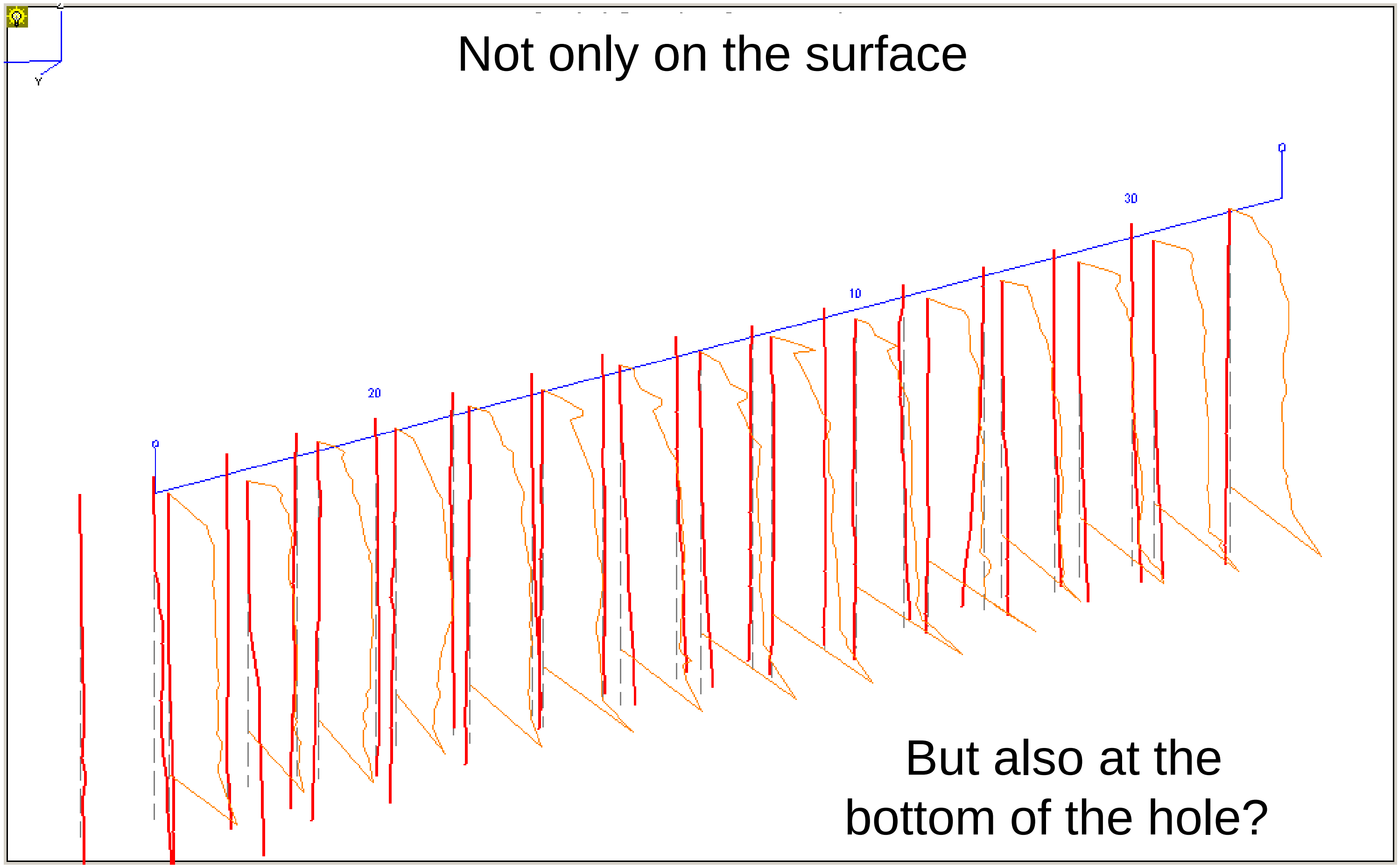
6 ½ inch diameter blasthole 54-74 Gyratory Allis Chamblis Granite

4 inch diameter blasthole Norberg C110 44 x34 Limestone

Monitor / Measure Performance

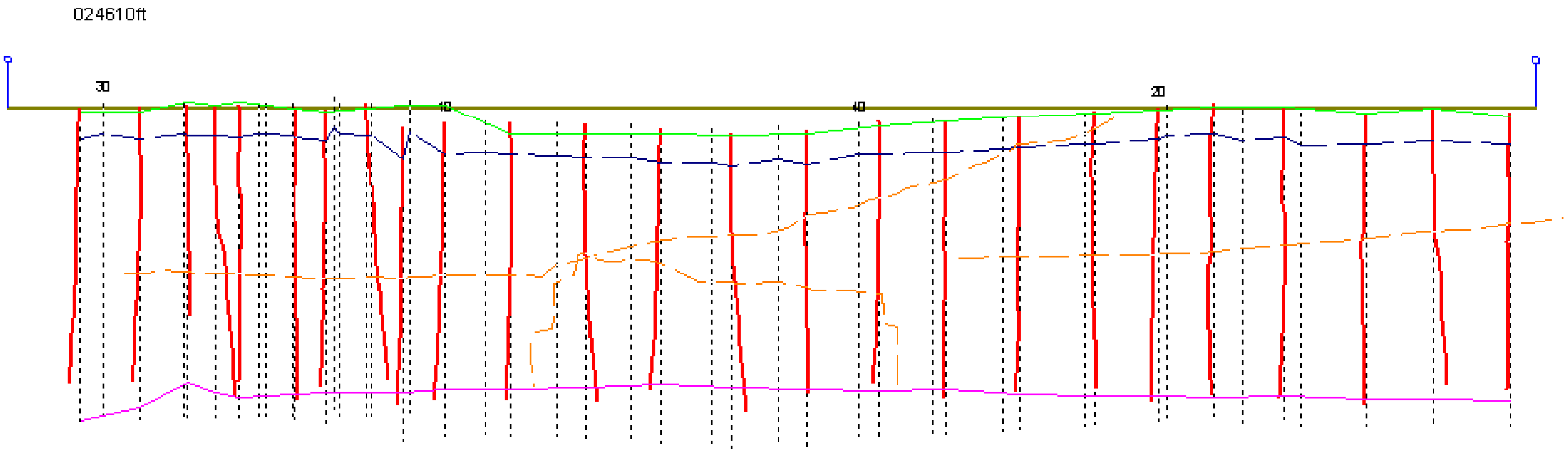
- **Pre-Blast**
  - ✓ **Drill hole integrity – borehole camera**
  - ✓ **Drill hole location and orientation in bench – borehole survey**
  - ✓ **Bench face shape, front row and inter-row burdens - laser survey**
- **During Blast**
  - ✓ **Rock movement; timing; stemming ejection**
  - ✓ **Efficiency of explosives; timing; inter-hole effects; stemming confinement.**
  - ✓ **Inter-hole effects; blast damage - Dynamic pressure measurement**
  - ✓ **Blast vibration and overpressure**

Accurately lay out and drill the blast pattern



Monitor / Measure Performance

Compare to design.



Recognize equipment limitations.

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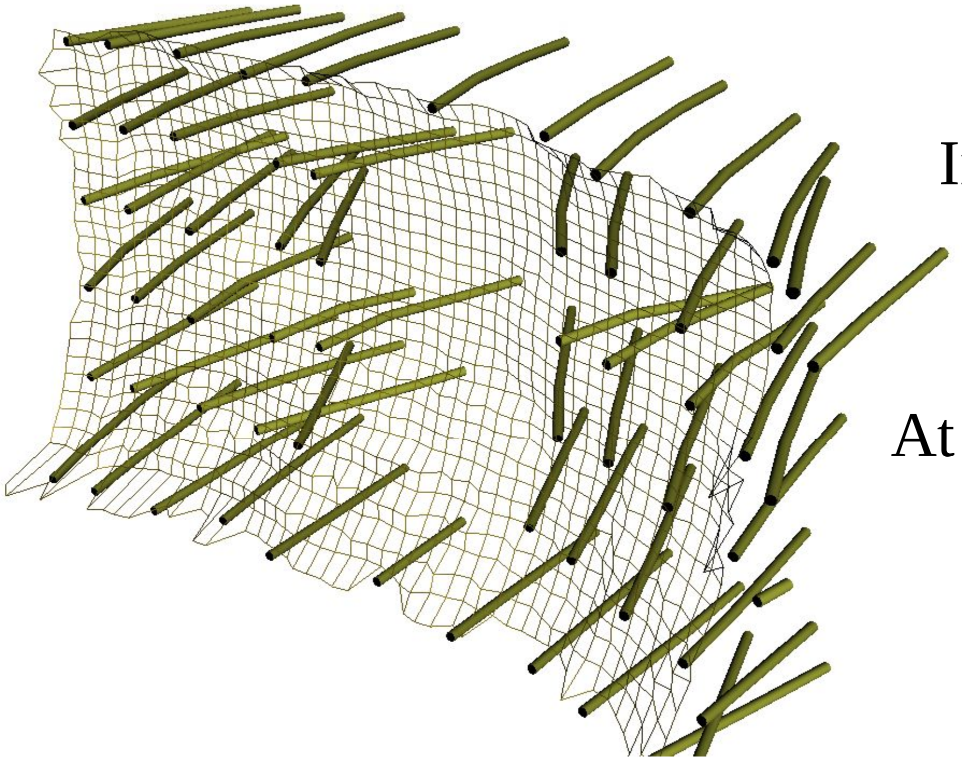
Heading - Underground Quarrying



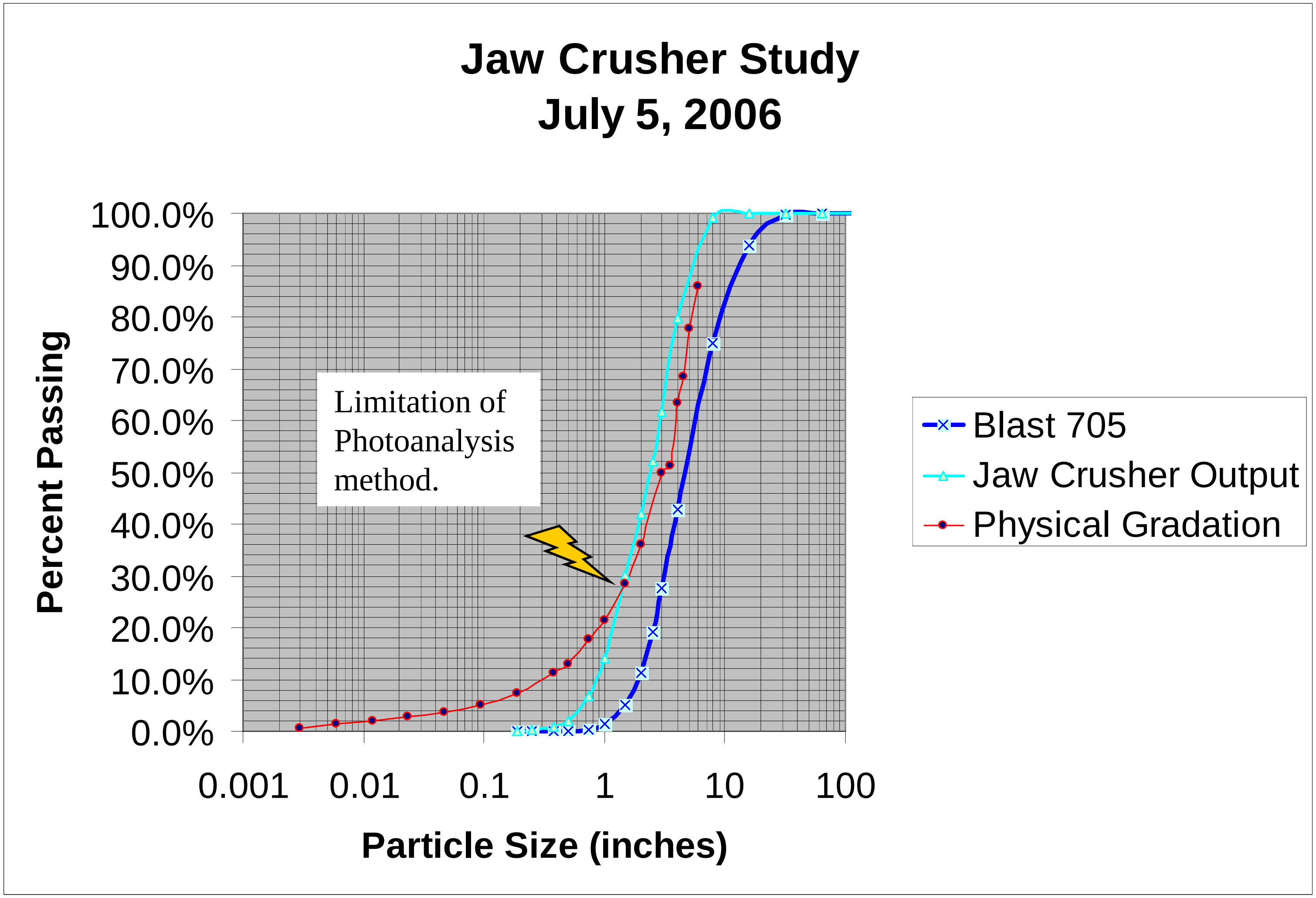
Into the face.

At the face.

Monitor / Measure Performance

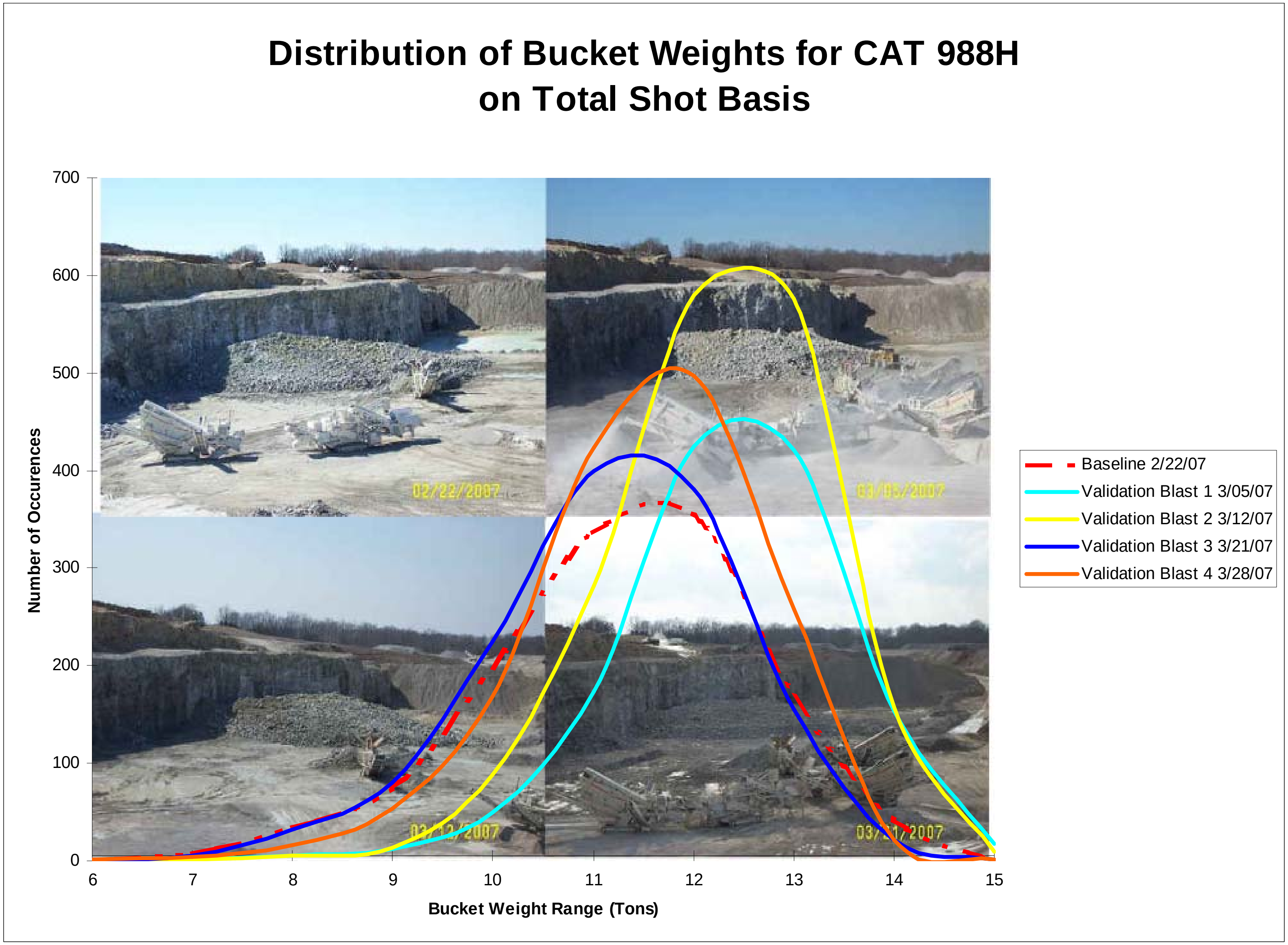
- **Post-Blast**
  - ✓ **Muckpile profile - Laser Survey**
  - ✓ **Fragmentation - Photoanalysis**
  - ✓ **Oversize – physical count**
    - Rehandle activities
  - ✓ **Equipment performance and costs**
    - Loading Rate
    - Bucket fill factor
    - Cycle Time
    - Crusher feed rate
    - Additional equipment
      - Loaders; Excavators, Rock Hammer etc

Fragmentation Photoanalysis

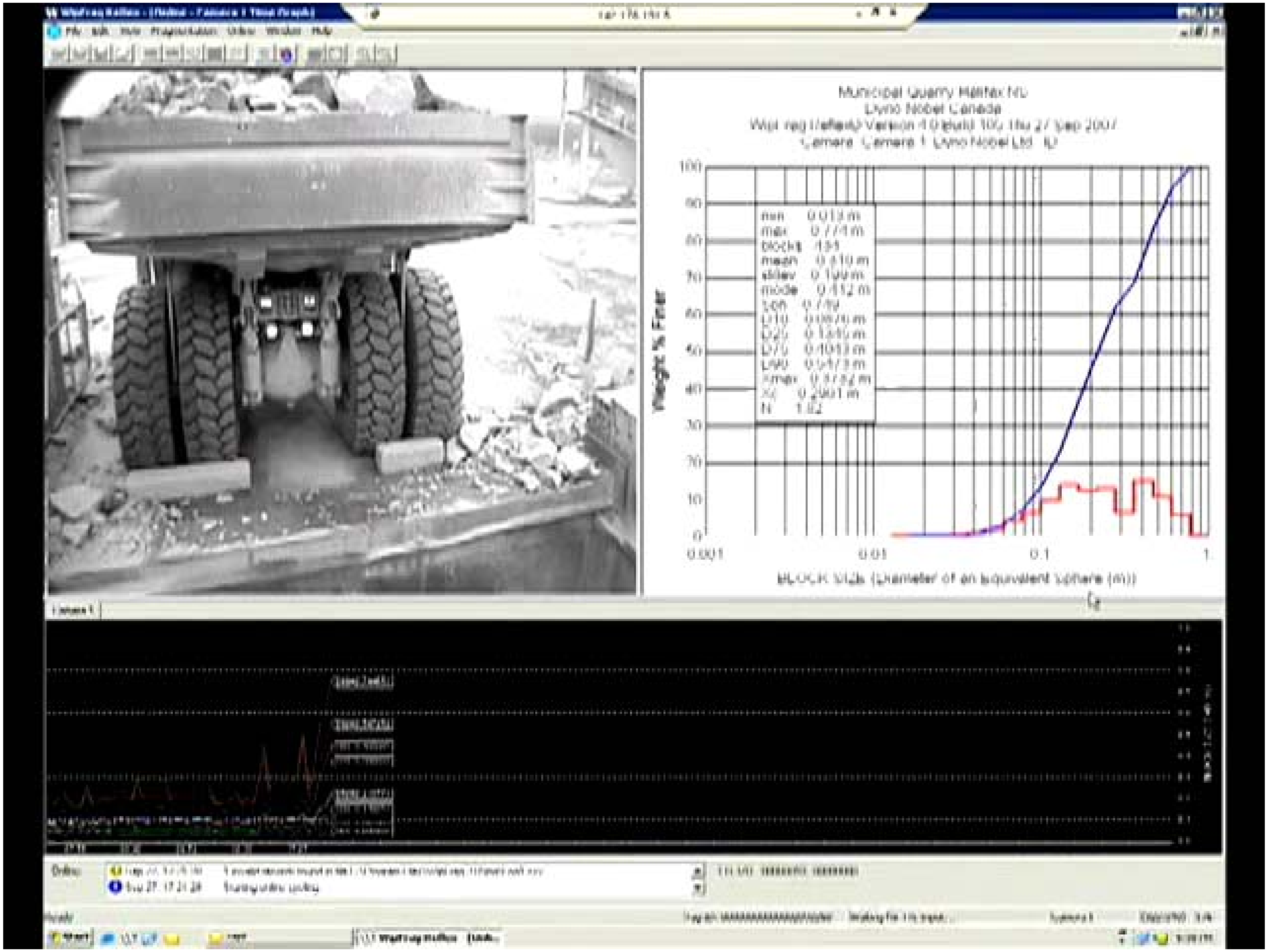


Monitoring Digability of the Muck Pile.

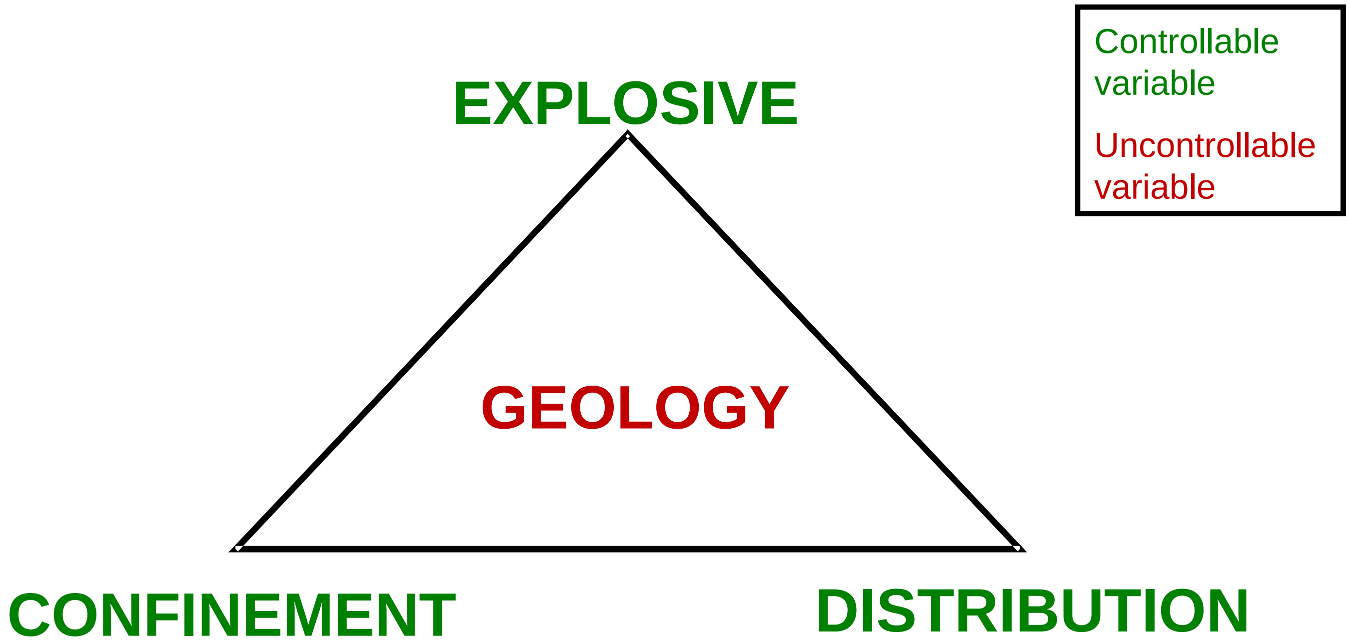
	CAT 988H								
Date	Operating Time hrs:min:sec	Daily Total To Jaw Tons	Average Cycle Time hrs:min:sec	Average Bucket Weight Tons	Buckets per shift #	Percent Buckets Over 12 ton	Down Time hrs:min:sec	Overall Crusher Feed Tons/hr	Adjusted Crusher Feed Tons/hr
16-Apr-07	3:46:29	1,058.04	0:02:19	10.69	99	15.2%	0:20:18	280.28	307.42
17-Apr-07	0:06:42	62.28	0:01:41	12.46	5	80.0%	0:00:00	553.60	553.60
18-Apr-07	7:18:57	2,373.04	0:02:07	11.41	208	34.1%	0:33:52	324.33	351.45
19-Apr-07	12:39:00	4,007.42	0:02:17	12.00	334	53.2%	2:32:37	316.79	414.20
20-Apr-07	12:30:30	4,287.54	0:02:10	12.32	348	62.4%	2:32:37	342.77	430.19
21-Apr-07	6:07:07	3,019.54	0:01:26	11.80	256	41.4%	0:00:00	493.50	493.50
23-Apr-07	12:13:38	5,003.14	0:01:42	11.53	434	38.0%	0:00:00	409.18	409.18
24-Apr-07	11:52:41	3,854.72	0:02:12	11.82	326	45.4%	2:10:19	324.52	397.14
25-Apr-07	11:01:32	4,011.14	0:02:01	12.15	330	61.2%	0:42:54	363.80	389.03
26-Apr-07	11:38:06	4,499.54	0:01:50	11.75	383	46.3%	0:10:28	386.72	392.61
27-Apr-07	10:55:22	4,333.42	0:01:49	12.00	361	52.6%	0:43:30	396.73	424.94
1-May-07	11:40:23	5,499.40	0:01:34	11.93	448	51.6%	1:14:14	471.12	526.97
2-May-07	12:23:11	6,003.16	0:01:32	12.33	477	67.7%	0:42:35	484.66	514.12
3-May-07	12:19:08	4,632.72	0:02:00	12.00	371	51.5%	NA	376.07	376.07
4-May-07	12:06:11	4,224.46	0:02:02	11.48	360	33.3%	3:15:45	349.04	477.85
7-May-07	11:28:10	4,061.82	0:02:04	11.81	344	46.2%	2:38:07	354.14	459.79
8-May-07	12:07:51	6,213.16	0:01:30	12.48	498	73.7%	0:18:02	512.18	525.19
9-May-07	12:19:24	6,125.36	0:01:34	12.20	502	61.6%	0:26:24	497.05	515.46
14-May-07	10:16:17	4,375.92	0:01:47	12.26	357	64.7%	1:20:05	426.03	489.66
15-May-07	11:54:27	3,380.00	0:02:09	12.03	281	56.6%	2:01:23	283.85	310.53
16-May-07	12:17:37	4,377.94	0:01:52	12.06	363	59.5%	2:38:45	356.12	453.78
17-May-07	11:22:25	4,809.70	0:01:53	12.02	399	54.4%	1:38:44	422.88	494.42
18-May-07	10:38:22	4,848.36	0:01:39	12.00	404	54.2%	0:17:43	455.70	468.70
Total	**241:03:30**	**95,061.82**			**7,888**		**26:18:22**		
Average			**0:01:50**	**12.05**		**52.4%**		**394.35**	**442.66**



Distribution of Bucket Weights for CAT 988H
on Total Shot Basis
Number of Occurences
700
600
500
400
300
200
100
0
6
7
8
9
10
11
12
13
14
15
Bucket Weight Range (Tons)
Baseline 2/22/07
Validation Blast 1 3/05/07
Validation Blast 2 3/12/07
Validation Blast 3 3/21/07
Validation Blast 4 3/28/07
02/22/2007


Dyno Nobel Canada
Weight % Finer
0.001
0.01
0.1
1
BLOCK SIZE (Diameter of an Equivalent Sphere (m))

Optimizing Blast Fragmentation



Blast Design Variables

Explosive
A controllable variable in blast design

- **What explosive is chosen to be used.**
  - ✓ **Density (g/cc)**
  - ✓ **Velocity of Detonation (ft/sec)**
  - ✓ **Energy (kcal/lb)**
  - ✓ **Water Resistance**
  - ✓ **Form**
    - Package
    - Bulk
      - Dry Blend / Free Flowing
      - Wet Blend / Augerable
      - Pumpable Blend

Confinement
A controllable variable in blast design

- **How the explosive energy is confined so that it can do work.**
  - ✓ **Amount of material surrounding the explosive in the drill hole**
    - Material between the drill hole and any static or dynamic free space.
  - ✓ **Distance of the drill hole from an open face.**
    - Burden
  - ✓ **Distance of drill holes relative to one another.**
    - Burden
    - Spacing
  - ✓ **Type and amount of stemming / non explosive decking**

Distribution
A controllable variable in blast design

- **How the explosive energy is distributed throughout the rock mass – vertically and horizontally to do work.**
  - ✓ **Diameter of the drill hole.**
    - Limits the diameter of explosive.
  - ✓ **Diameter of the explosive.**
    - Package explosive can limit the effective diameter of the blasthole.
  - ✓ **Depth of the drill hole and the amount loaded.**
    - Accuracy
    - Explosive deck(s)
  - ✓ **Orientation of drill holes**
    - Relative to one another – staggered, in-line

Keys to Optimizing Explosive Performance

- **Choose Optimum Explosive Type.**
- **Optimize the distribution of the explosive’s energy.**
- **Optimize confinement of the explosive’s energy.**

Keys to Optimizing Explosive Performance

- **Explosive Energy Distribution Optimization**
  - ✓ **Increased distribution reduces overall rock fragment size.**
  - ✓ **Decreased distribution increases overall rock fragment size.**
  - ✓ **Even distribution achieves uniform fragmentation.**
  - ✓ **Important to maintain as even distribution from top to bottom of bench as possible.**
  - ✓ **Widely spaced jointed rock mass requires reduced patterns.**

Keys to Optimizing Explosive Performance

Explosive Distribution

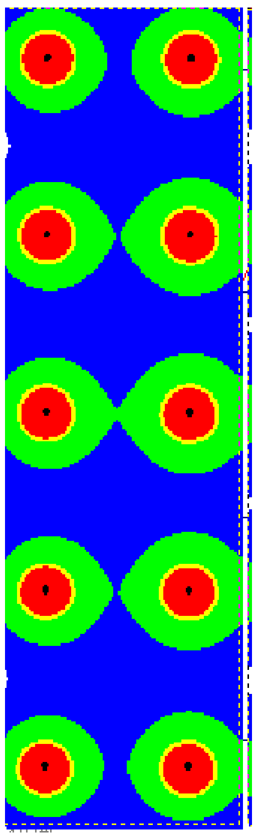
Hole Diameter (in)	4	6	7	9
Bench height (ft) [H]	40	40	40	40
Burden (ft) [B]	10	15	17	21
Spacing (ft)	12	17	20	26
Stemming (ft) [T]	7	10.5	12	15
Subdrill (ft)	3	4.5	5	6.5
Explosive	ANFO	ANFO	ANFO	ANFO
Powder Factor (tons/lb.)	2.02	2.02	2.03	2.07
Bench Stiffness (H/B)	4	2.7	2.4	1.9
Explosive Distribution (1-T/H)x100	83%	74%	70%	63%
Energy Factor (kcal/ton)	200	200	199	195
Fragmentation F80*	25 inch	29 inch	29.5 inch	31 inch

Equivalent Powder Factor or Energy Factors $\neq$ Equivalent Explosive Distribution

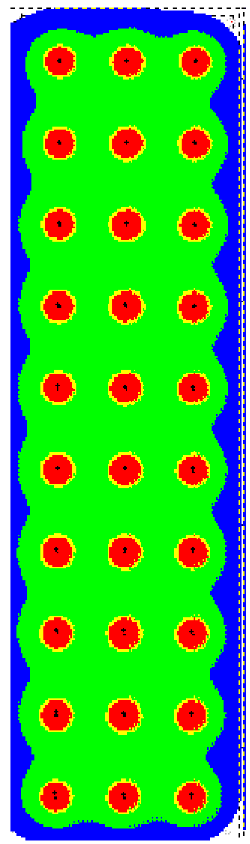
*more dramatic change in uniformity.

Energy Distribution Comparison – Planar

9 inch, 21ft x 26 ft

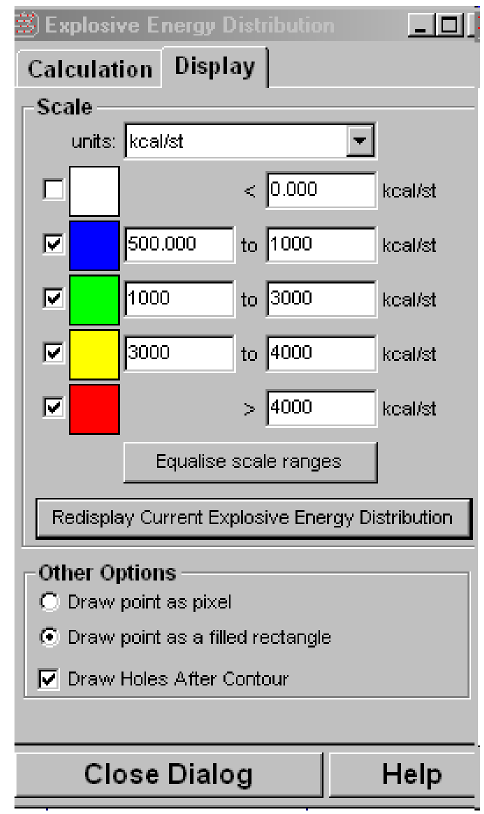


4 inch, 10 ft x 12 ft



Horizontal slices of bench @ 32 ft down from surface

Equivalent overall powder factors



Keys to Optimizing Explosive Performance

- **Explosive Energy Confinement Optimization**
  - ✓ **Explosive Energy must be confined long enough after detonation to establish fractures and displace the rock mass.**
    - Design timing to provide adequate relief without loss of confinement.
  - ✓ **Control paths of least resistance for explosive energy**
    - load according to geology and face conditions
    - use adequate and proper stemming materials
  - ✓ **Use multiple primers to insure explosive column performance.**
  - ✓ **Accurately layout and drill the blast pattern**
  - ✓ **Reminder:**
    - over confinement = excessive vibration
    - under confinement = excessive air blast

Statistical Approach to Integrating Blasting into the Quarrying Process
Cement Producer – New York

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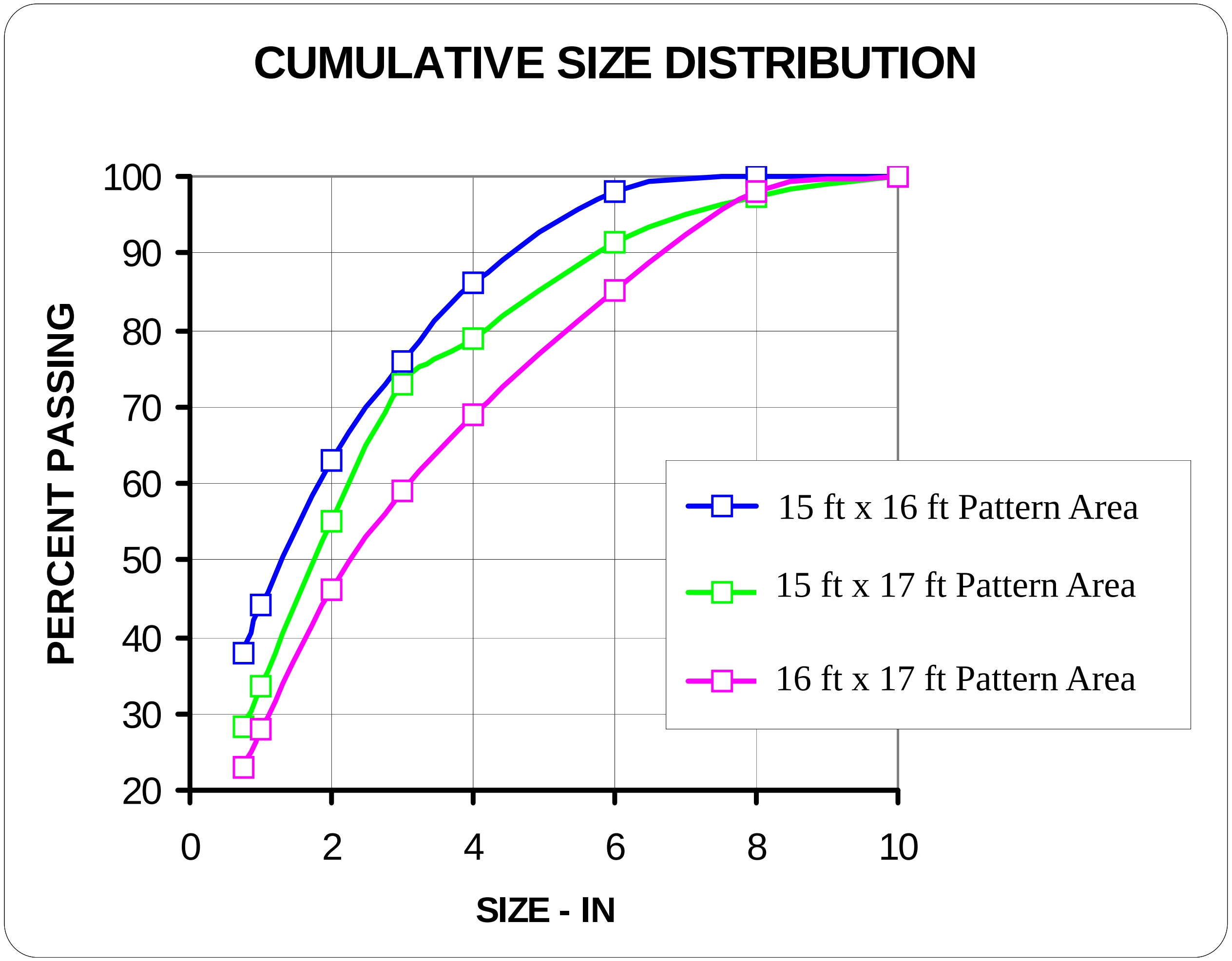
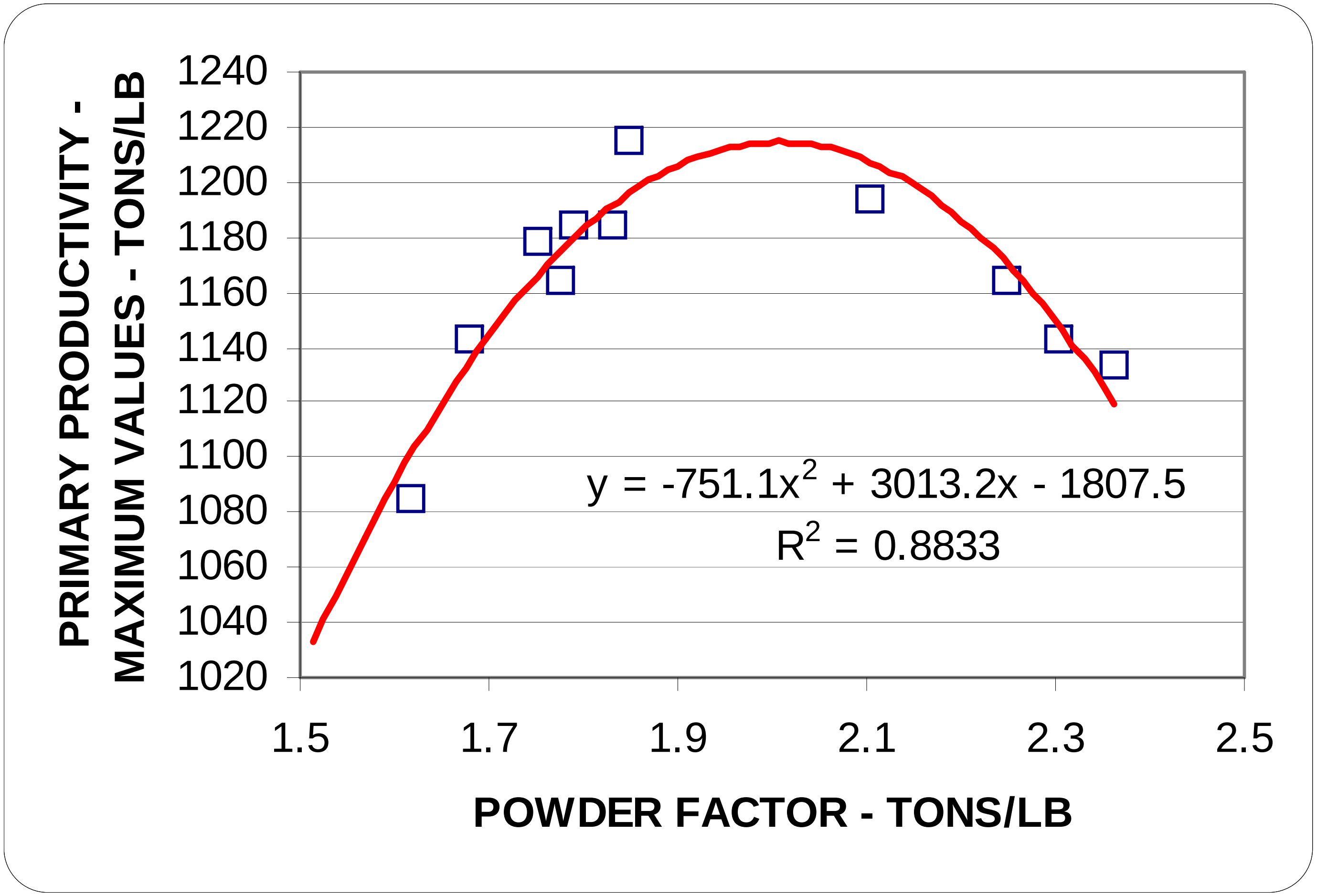
Gradation of ROQ vs Blast Pattern



Statistical Analysis



Evaluation of Repumpable Emulsion – Case Study
Granite Quarry – Macon, GA

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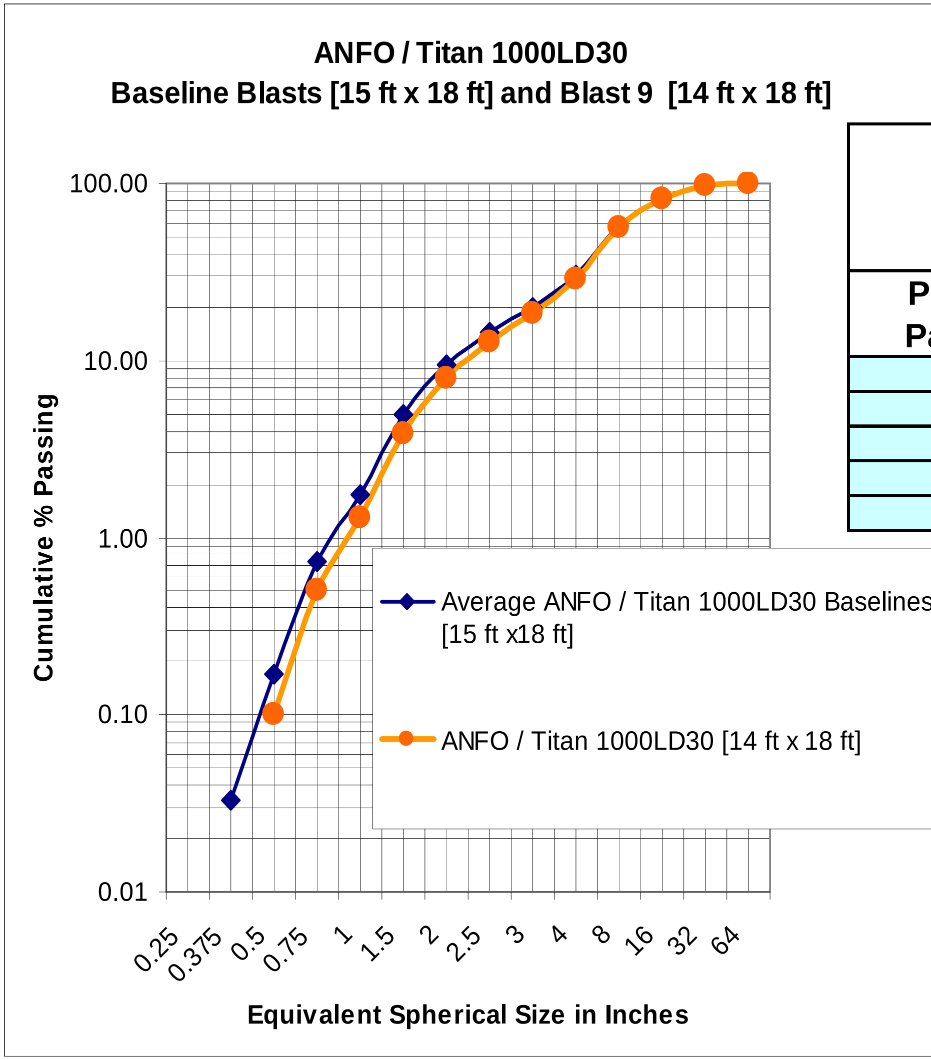
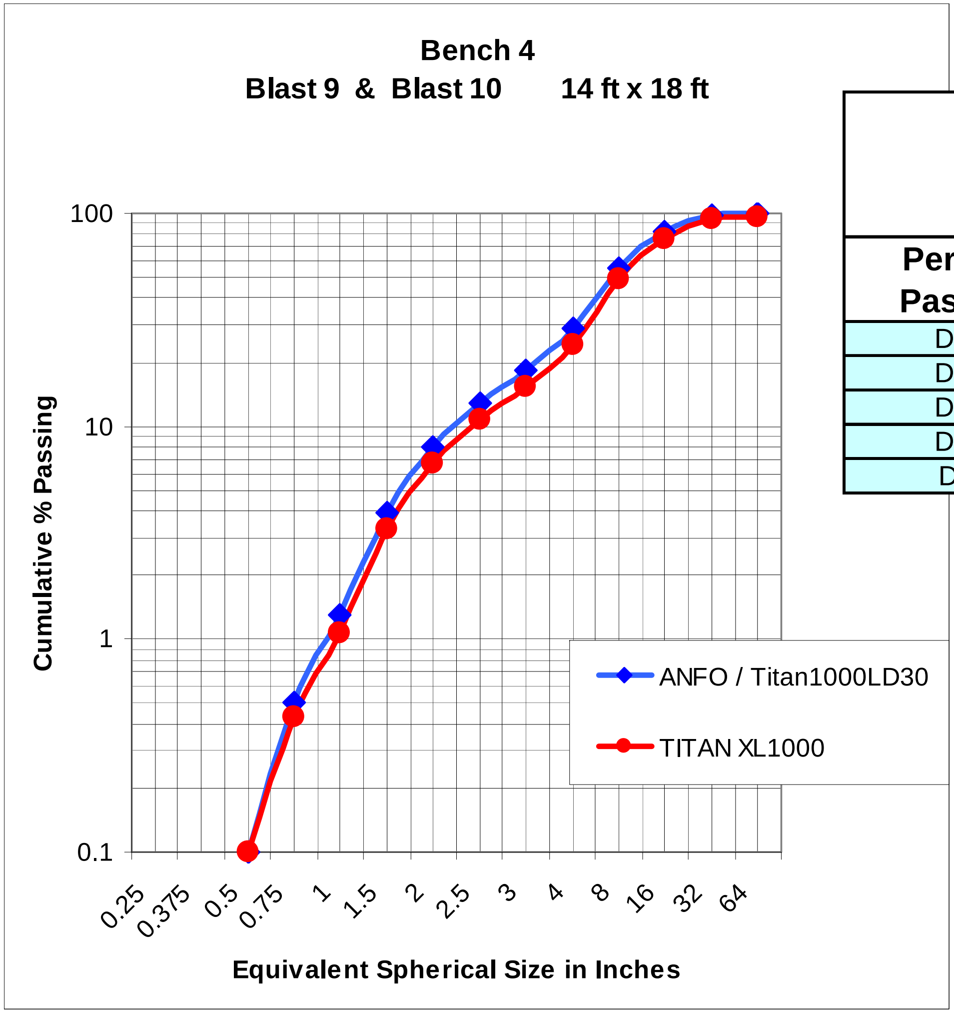
Fragmentation Dictated by Local Geology



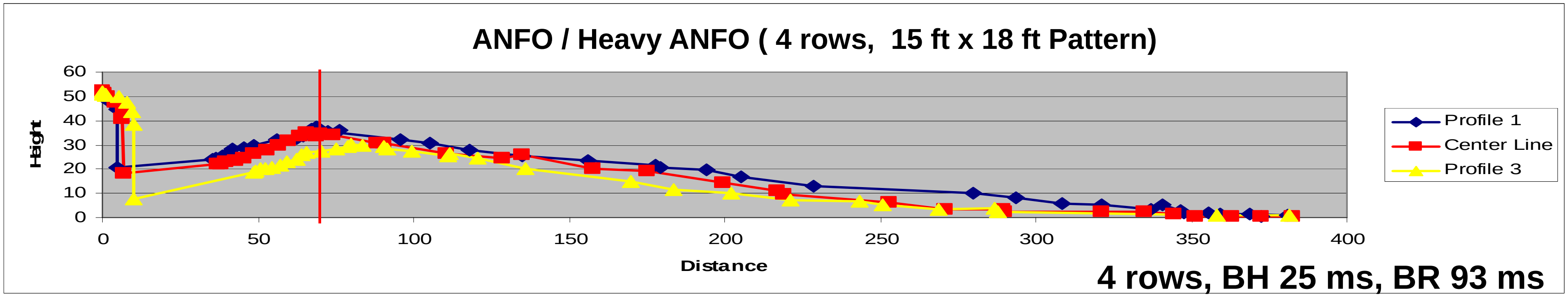
Fragmentation ANFO / TITAN XL 1000LD30 Optimization Test Blast			Baseline
Percent Passing	Blast # 50		Average
D10	2.2		2.04
D25	3.7		3.39
D50	6.9		6.45
D75	13.3		12.68
D90	20.5		20.60

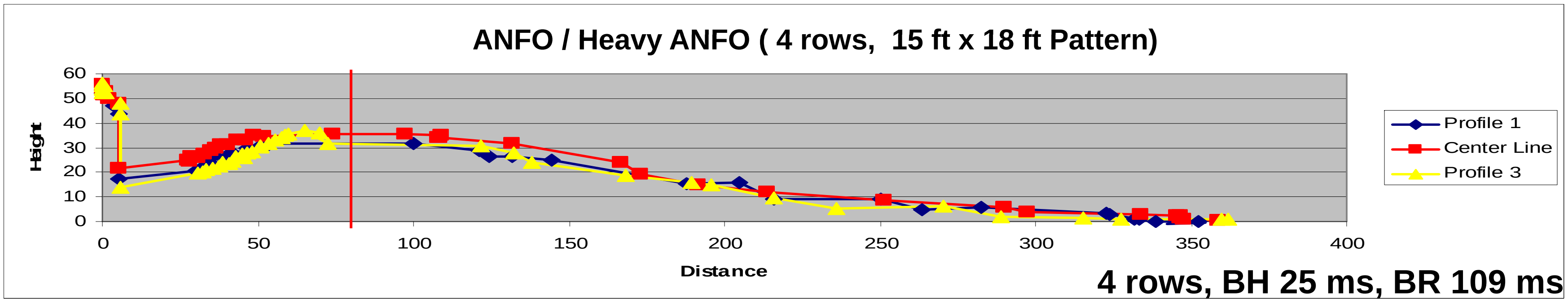
Fragmentation Dictated by Local Geology

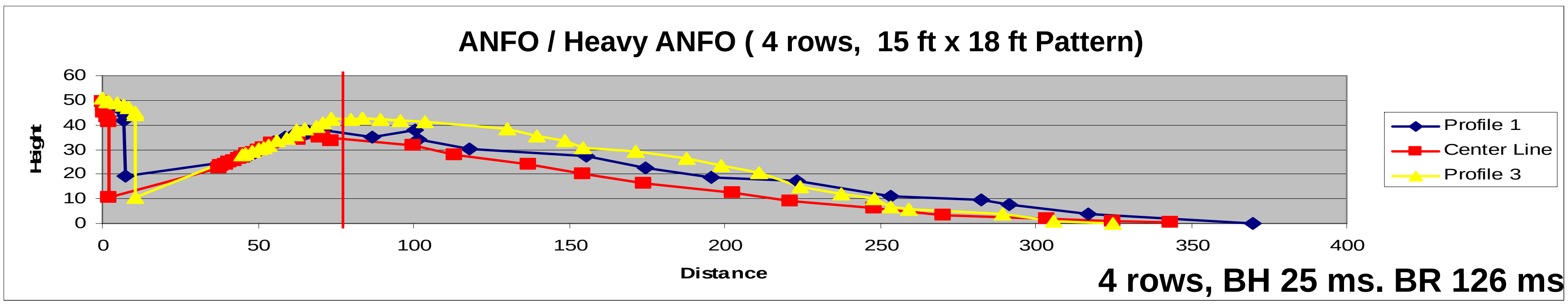


Fragmentation TITAN XL 1000 Optimization Test Blast			Baseline
Percent Passing	Blast # 02-04		Average
D10	2.5		2.04
D25	4.3		3.39
D50	8.4		6.45
D75	16.5		12.68
D90	27.0		20.60

Muck Pile Profile vs Relief Time







Electronic Detonator – Case Study
Aggregate Quarry - Nova Scotia, Canada

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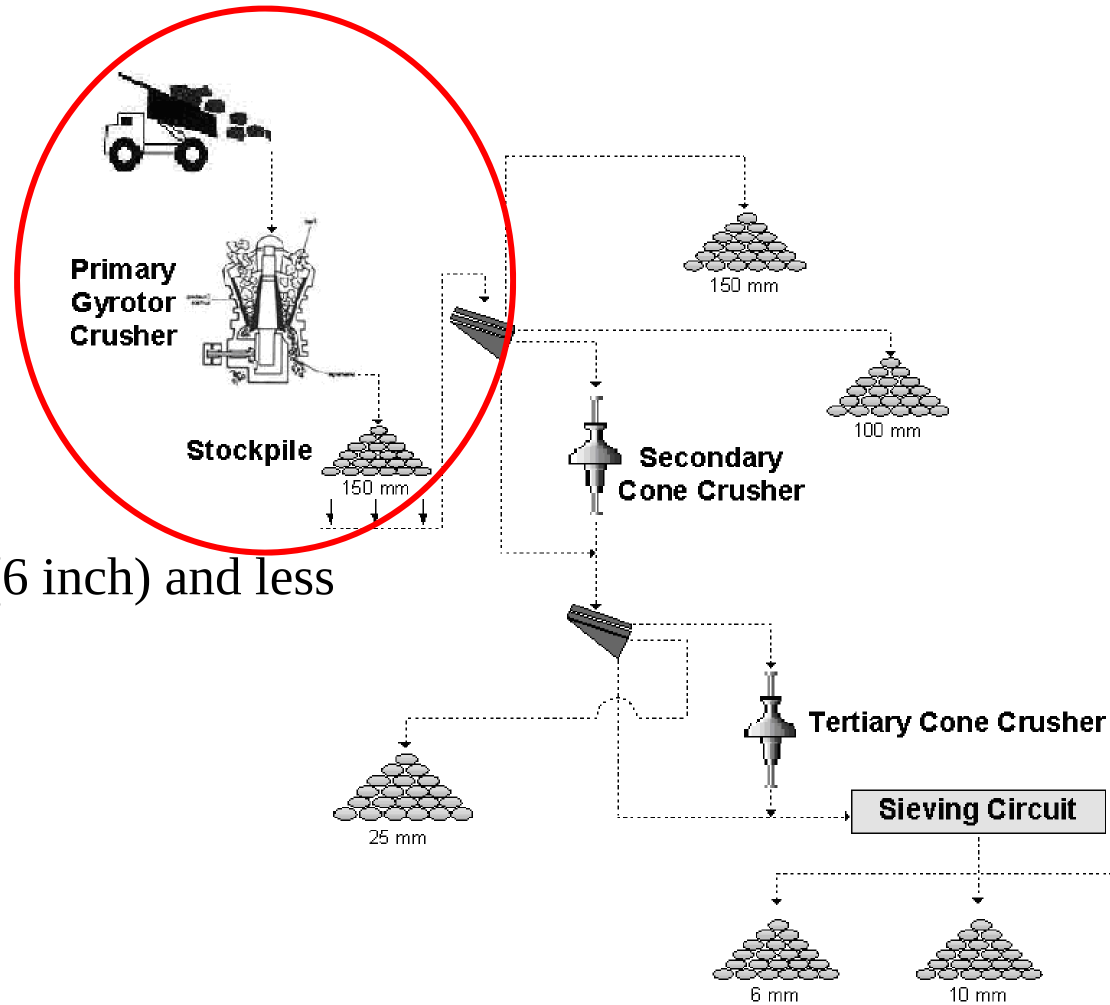
Simplified Process Flow

Svedala model 42-65.

Reduced to 150 mm (6 inch) and less

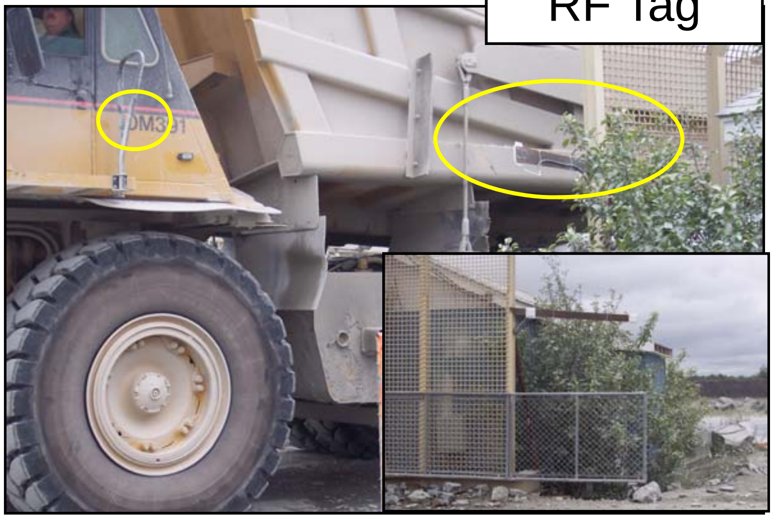


Fragmentation Measurement

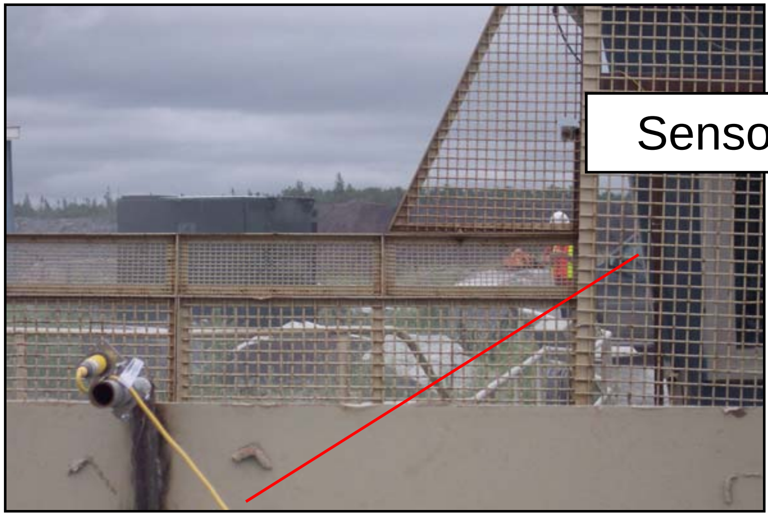
- **Reflex system**

Camera

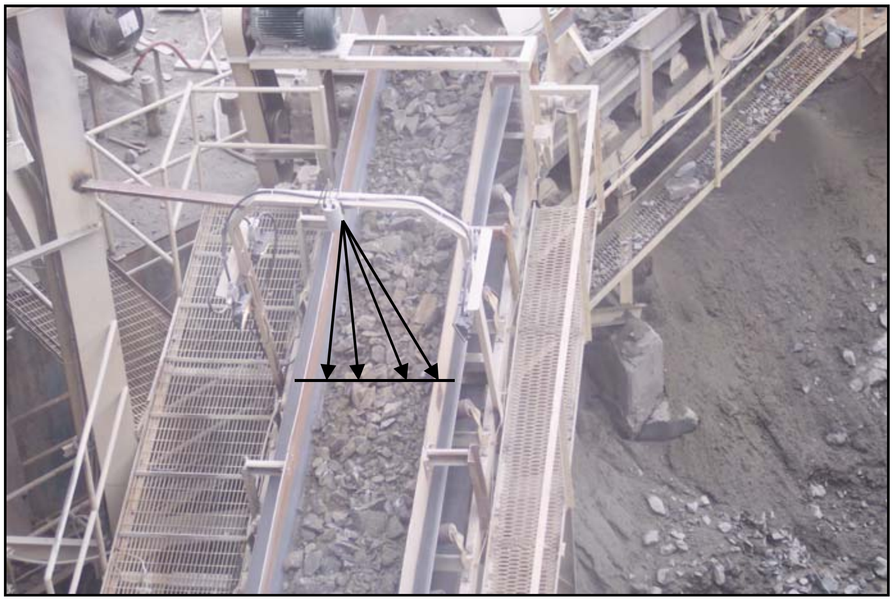
RF Tag



Sensors

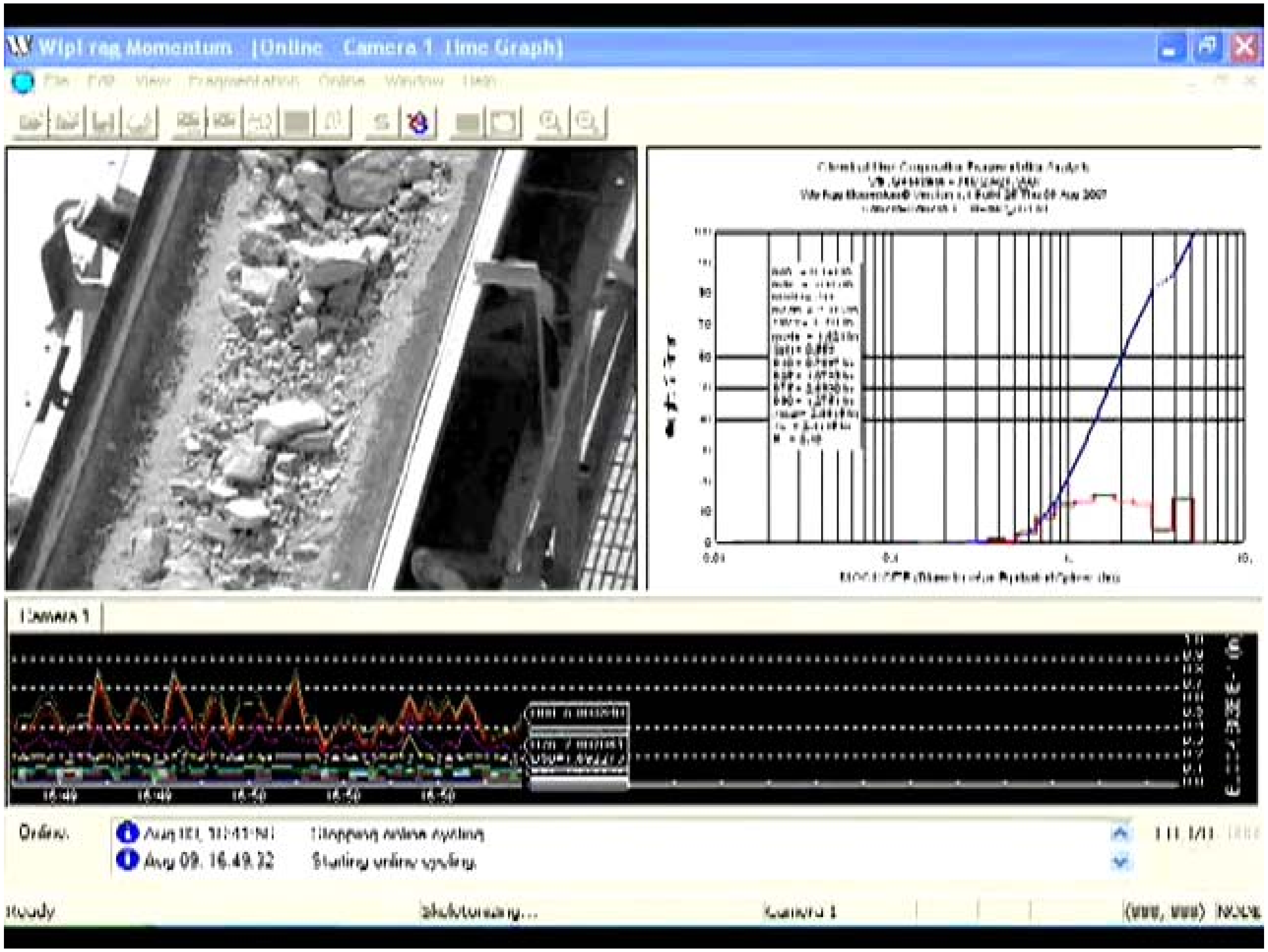


Fragmentation Measurement



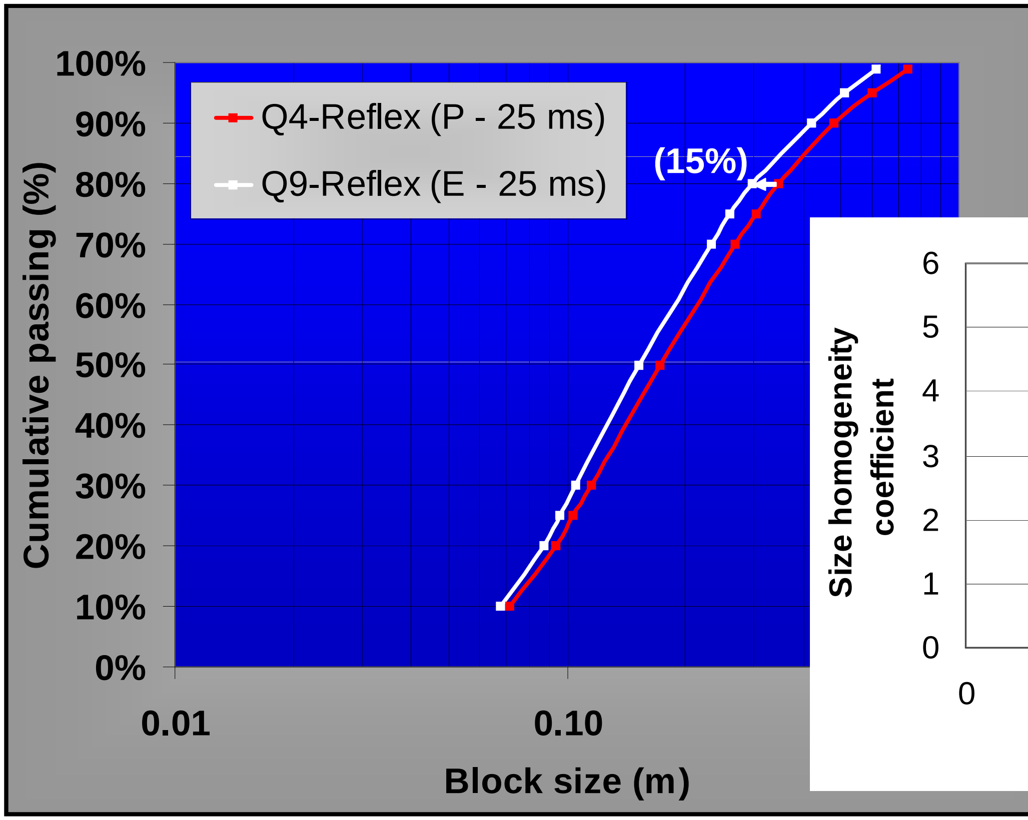
- **Momentum System**
  - ✓ **One image per second**
  - ✓ **Monitoring only when there is material on the conveyor belt.**
  - ✓ **Day shift monitoring only.**

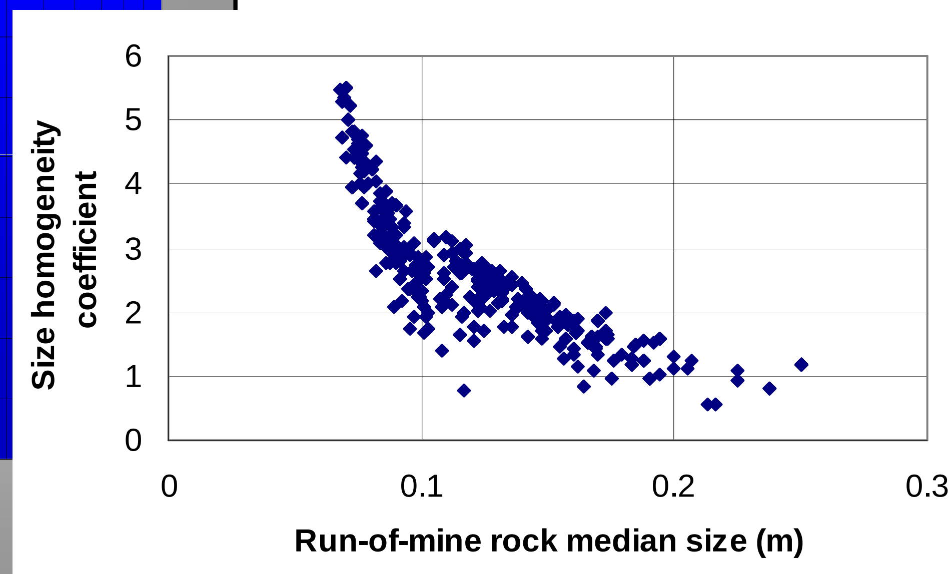
Momentum Fragmentation Analysis System



Impact of Electronic Detonators

- Blast Pattern and Powder Factor maintained constant.
  - ✓ 6 1/2 inch diameter hole; PF 1.68 lb/cu yd.
- Finer and more uniform rock size distribution





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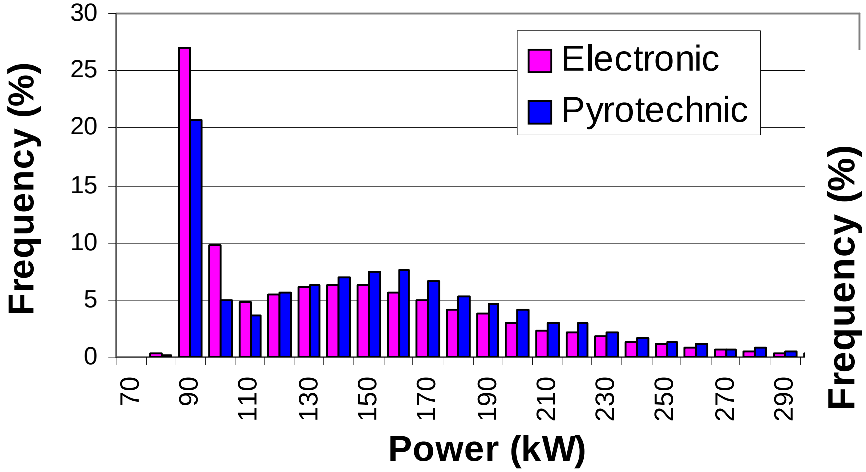
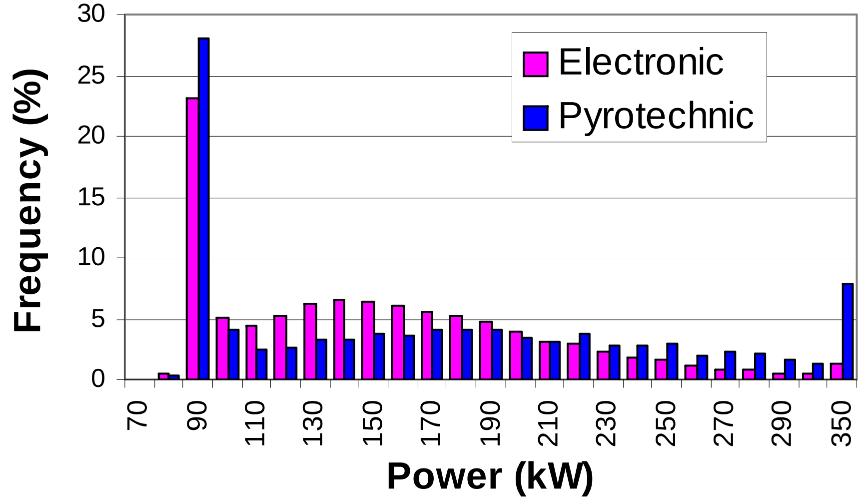
Impact of Electronic Detonators

- **Ten percent (10%) energy saving at primary crushing**

Soft rock

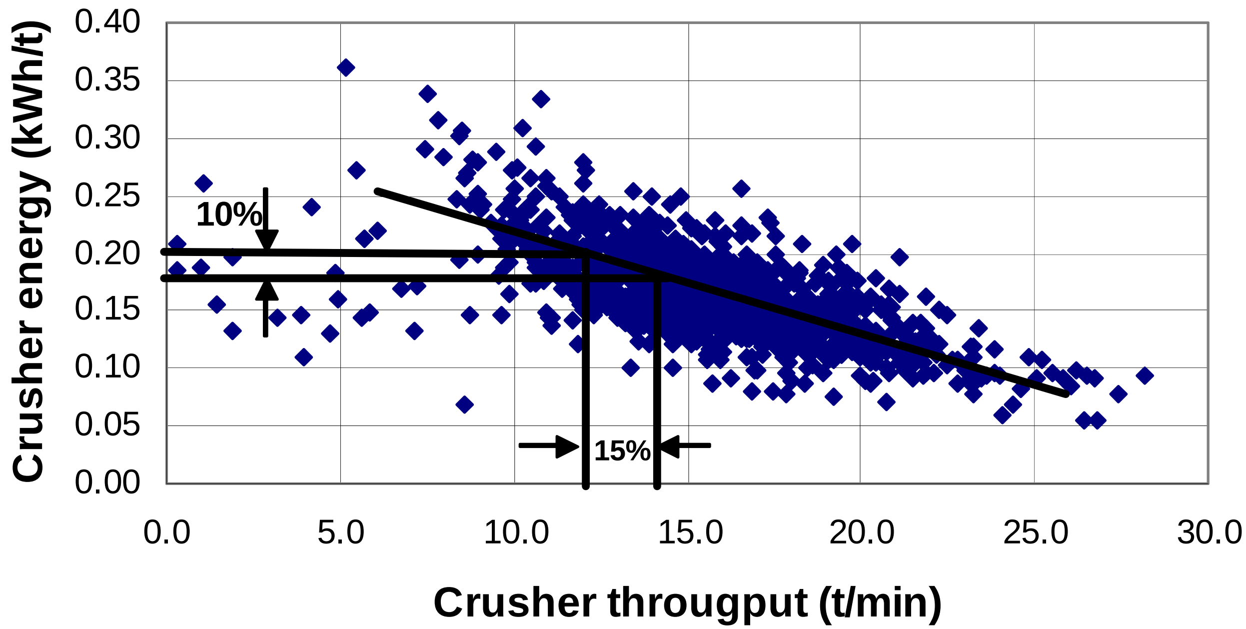


Medium rock



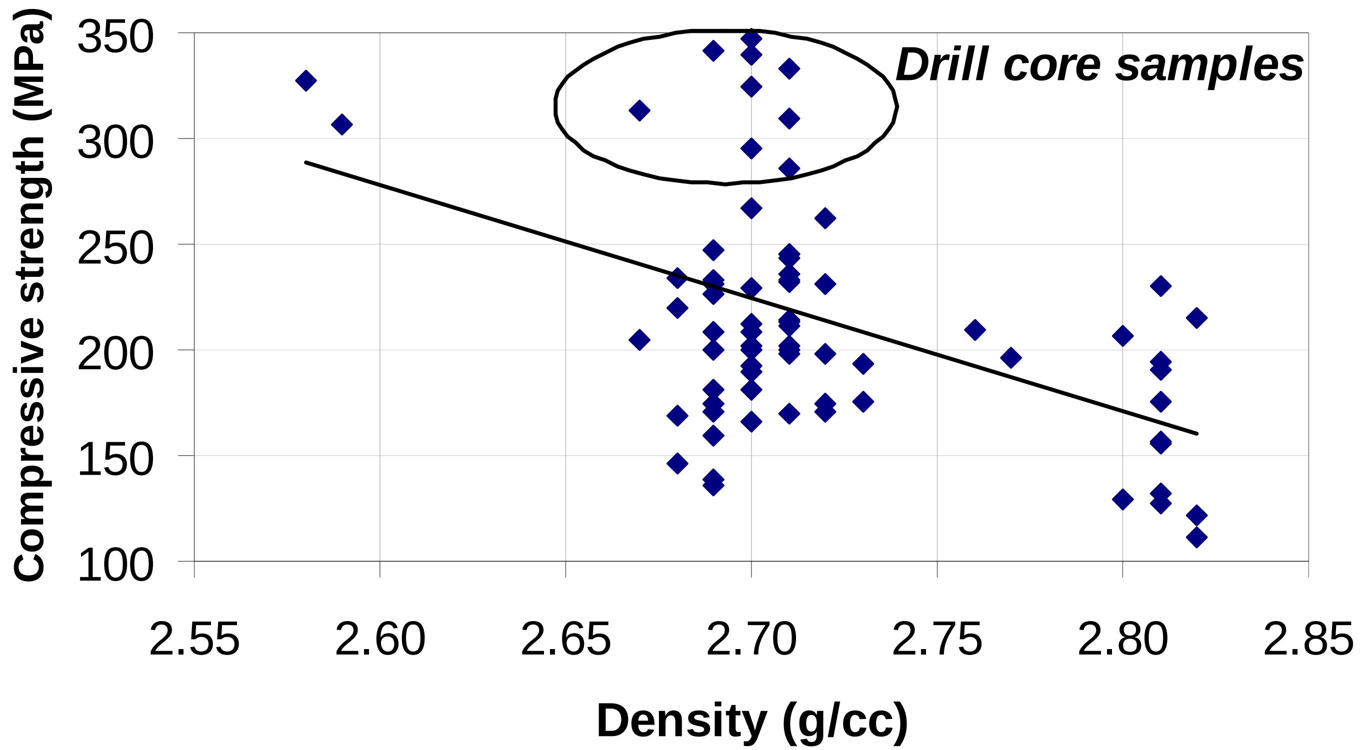
Impact of Electronic Detonators

- Fifteen percent (15%) productivity increase at primary crushing.
- Ten percent (10%) reduction in crusher energy.

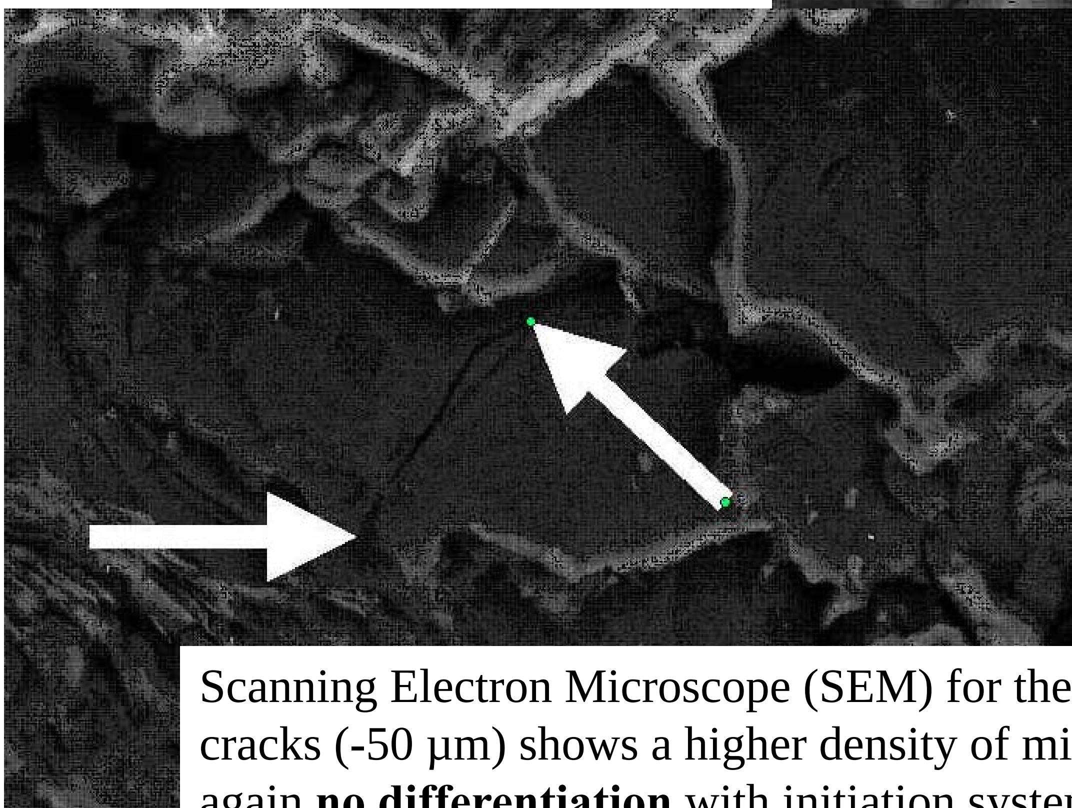


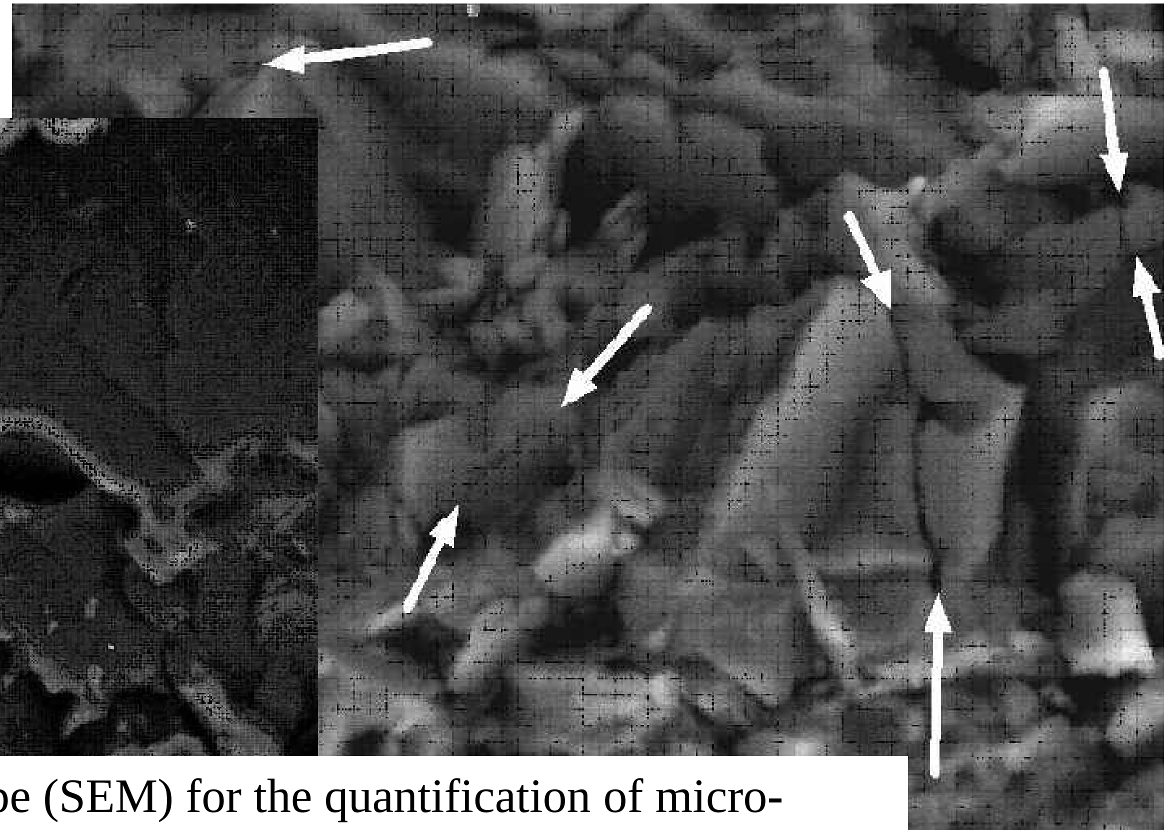
Blast-induced rock damage evaluation

A 30% tensile & compressive strength reduction was found in the rock after blasting. **No difference** was seen between initiation systems.



Blast-induced rock damage evaluation





Scanning Electron Microscope (SEM) for the quantification of micro-cracks (-50 µm) shows a higher density of micro-cracks after blasting . But again **<u>no differentiation</u>** with initiation system type.

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