Explosive Characteristics and Performance

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QUARRY ACADEMY

Improving Processes. Instilling Expertise.

DYNO Dyno Nobel

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Course Agenda

- ***Explosive Properties***
- ***Detonation Properties***
- ***Explosive types***
  - ✓ ***Characteristics***
  - ✓ ***Available technologies***
- ***Explosive selection to meet blasting objectives***
- ***Explosive selection for the most efficient "crusher"***

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Explosive Properties

- Physical properties
  - Give an indication of the application in which they can be used
- Detonation properties
  - These properties are used to describe the performance of explosives
- Safety properties
  - These describe the handling requirements for different products

All properties are important when selecting explosives.

Physical Properties

- Loaded Density
- Water resistance
- Chemical stability
- Fume characteristics
- Sleep time

Loaded Density

- Important property for explosive selection
- Density below 1.0 g/cm^3 means explosive may float in water
  - High viscosity products such a homogenized emulsion
  - Loading process such as repump emulsion
- Increasing density leads to increasing Velocity of Detonation (VoD) up towards critical density
- Increasing density leads to increasing detonation pressure
- Higher density for non-ideal explosives risks dead pressing
- Determine loading density (kg/m or lb/ft)

Water Resistance

Ability of explosive ability to withstand exposure to water without losing sensitivity or efficiency

- Wide variation:
  - ANFO has none
  - Emulsion is excellent
- Dependent on water conditions
  - Static or dynamic water
  - pH will affect emulsion sleep time
- Orange-Brown Nitrous Oxide fumes post blast is indication of water damage to explosive
- Water resistance of explosives can be improved by use of hole liners, but usually at the risk of reduced charge per meter of blast hole

Chemical Stability

Defined as the ability to remain chemically unchanged when stored correctly. It is a key parameter in shelf life of many products

Factors affecting shelf life include:

- Formulation/Raw material quality
- Packaging
- Temperature and humidity of storage environment
- Contamination

Characteristic signs of deterioration include:

- Crystallization
- Increased viscosity and/or density
- Color change (e.g. bulk emulsions go cloudy as crystallization increases)
- Poor field performance

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Fume Characteristics

- Oxygen balanced explosives yield non toxic gases
  - (CO_2, N_2 and H_2O)

Minor quantities of toxic gases also produced

  - Oxides of nitrogen (NO_x) result from an excess of oxygen in the formulation (oxygen positive)
  - Carbon monoxide (CO) results from a deficiency of oxygen in the explosive (oxygen negative)

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Sleep Time

- Wet or dry ground
- Product selection
- Ground type
  - Reactive material to explosive material
  - Exposure to the reactive material as with bulk products
  - Hot temperature ground (150º F)

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Detonation Properties

- Velocity of detonation (VoD)
- Detonation pressure
- Energy/strength
- Critical diameter
- Confinement

Velocity of Detonation (VoD)

Speed that the detonation wave travels through the explosive, usually expressed in metres per second (m/s) or feet per second (ft/s)

- Influenced by:
  - Rock Type
  - Charge diameter
  - Explosive density
  - Explosive formulation
  - Particle size
  - Degree of confinement
  - Primer (size and type)
- VoD will influence how the energy is released from the explosive (i.e. the partition of energy into shock and heave)

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Velocity of Detonation (VoD)

VoD is a guide to determining the efficiency of the explosive

- Comparison of VoD results should be done within the context of the particular blasting situation (i.e. same mine, same rock type). For Example, ANFO VoDs vary from 2500 to 4500 m/s (8200-14700 ft/s) depending on hole diameter in the same rock
- VoD data should be seen as a statistical variable (i.e. get multiple data wherever possible) to allow for:
  - Rock type variation
  - Charging variation
  - Data capture system

Detonation Pressure P_d

Pressure in the detonation reaction zone as it progresses along a charge, expressed in MPa. This is what generates the shock pulse in rock

P_d estimation for commercial explosives:

$$P_d = 0.25 \times VoD^2 \times \rho$$

eg. ANFO at ρ = 0.85g/cc and VOD = 4000m/s (13123 ft/s)

$$P_d = 0.25 \times 4000^2 \times 0.85$$

= 3400 Mpa

= 34 Kbars

= 499,800 psi

Available Explosives Energy

The energy that an explosive is able to deliver to do useful work:

- Energy delivered to the rock mass before the gasses vent to the atmosphere (Calculated using thermodynamic codes)
- Effective energy is the energy transformed into useful rock fragmentation and rock displacement
- Actual amount of energy delivered in any blast is unknown as too many variables exist
- One critical factor is the cut off pressure assumed in any energy calculation
  - Changing the cut off pressure will change the energy attributed to an explosive

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Absolute Weight Strength (AWS)

This is the theoretical absolute energy available, based on the ingredients of the explosive

- Energy calculated by Thermodynamic Codes (ideal)
  (i.e. computer models of the detonation chemistry and energy of the reactions)
- Usually quoted in MJ/kg of explosive
- AWS of ANFO is 880 cal/g for 94% AN and 6% Fuel Oil
- Explosive efficiency varies from 35% to 90% of maximum energy (this is the actual energy delivered in a blast is 35% to 90% of theoretical maximum)

Relative Weight Strength (RWS)

This is the ratio of energies of a unit weight of explosive compared to an equal weight of ANFO

- RWS for an explosive is the AWS of the explosive divided by the AWS of ANFO, expressed as a percentage:

$$RWS_{explosive} = \frac{AWS_{explosive} \times 100}{AWS_{ANFO}}$$

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Absolute Bulk Strength (ABS)

The energy available in a unit volume of explosive

- ABS for an explosive is its AWS multiplied by its density

$$\mathbf{ABS_{explosive} = AWS_{explosive} \times \rho_{explosive}}$$

Where $\rho_{explosive}$ is the density of the explosive and ABS units are in cal / cc

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Relative Bulk Strength (RBS)

The ratio of the energies available in a given volume of explosive compared to an equal volume of ANFO

- RBS for an explosive is the ABS of the explosive divided by the ABS of ANFO, expressed as a percentage:

$$\mathbf{RBS_{explosive} = \frac{ABS_{explosive} \times 100}{ABS_{ANFO}}}$$

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Critical Diameter = D_{crit}

Defined as the minimum diameter at which a stable detonation can propagate.

- **Ideal explosives, 1 mm (0.04 inch)**
- **Non-ideal explosives, can be up to 200 mm (8 inch)**
- **D_{crit} depends on the level of confinement**

D_{crit} is important for determining hole size/explosive type compatibility

- **D_{crit} is determined predominantly by the size of the reaction zone**
- **Density also has an effect on D_{crit}**

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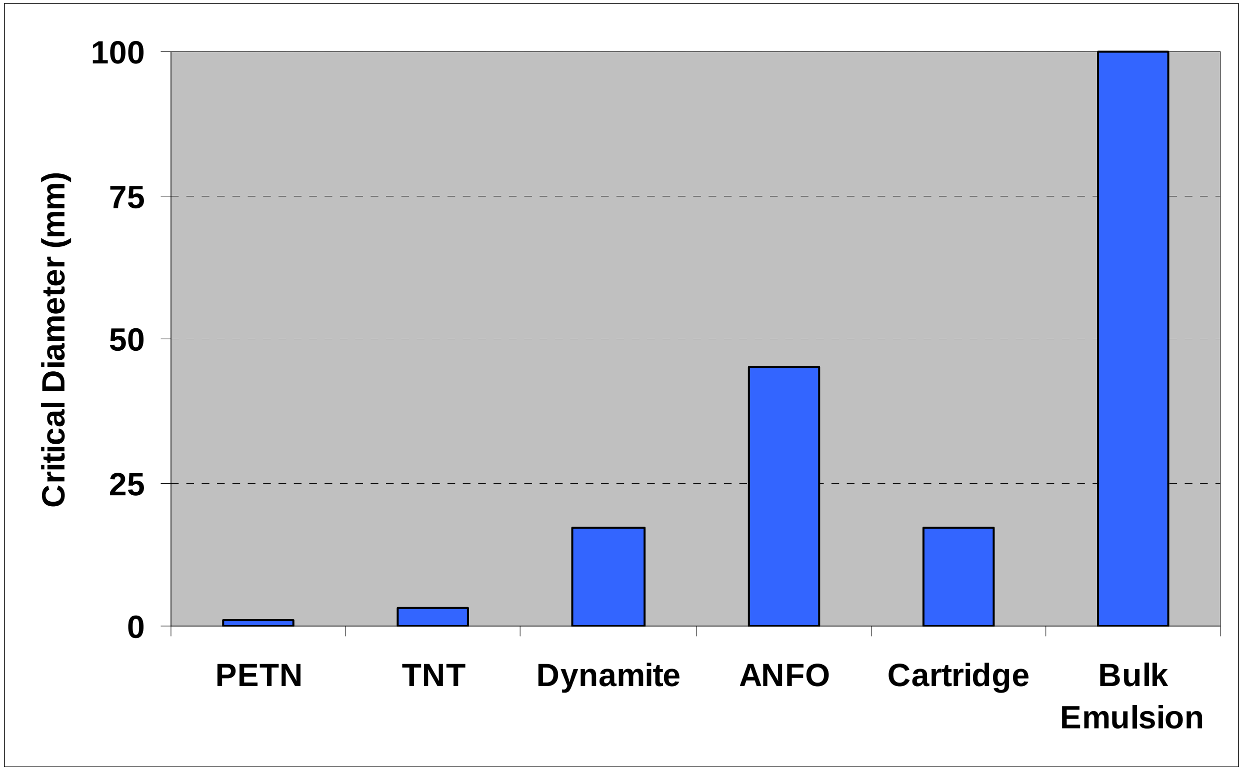
Critical Diameter



Molecular explosives

Non-ideal explosives

Confinement

Confinement refers to the strength of the walls of the container in which the explosive is detonating.

Standards are:

- Unconfined - usually taken as a cardboard tube
- Confined - usually taken as a Schedule 40 Steel tube

Increasing confinement:

- Increases the VOD
- Maintains steady state detonation / reaction
- Therefore can determine efficiency of energy release and potential for NO_x fumes

Sensitivity

Defined as ease of initiation of explosive (i.e. minimum energy required to initiate detonation)

- Varies with composition, diameter, temperature and pressure
- High Explosive (1.1D) defined as sensitive to No 8 strength detonator or 25 gr/fr cord,
- Blasting Agent 1.5D requires a booster for initiation
- Can be altered by incorrect use
  - Some blasting agents can become detonating cord sensitive – lateral prime
  - Some blasting agents can be desensitized by detonating cord – lateral dead-press

Testing includes:

- Minimum primer, Critical diameter, Impact, Critical density, Frcition, Gap test

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ANFO

Advantages

- Easy to manufacture
- Cost effective
- Simplest and most widely used explosive
- Low density

Disadvantages

- No water resistance
- Fume generation
- Low density

ANFO

Physical properties

Bulk poured density: 0.82 - 0.85 g/cm^3 (dependent on AN source)

- Blow loaded density: 0.85 to +1.05 g/cm^3
- Water resistance: none actually hydroscopic

Detonation properties

- AWS = 880 cal/g (401 Kcal/lb)
- RWS = 100
- RBS = 100 - 115
- VOD = 2500 - 4500 m/s (8200 – 14700 ft/s)
- High gas (heave) energy potential

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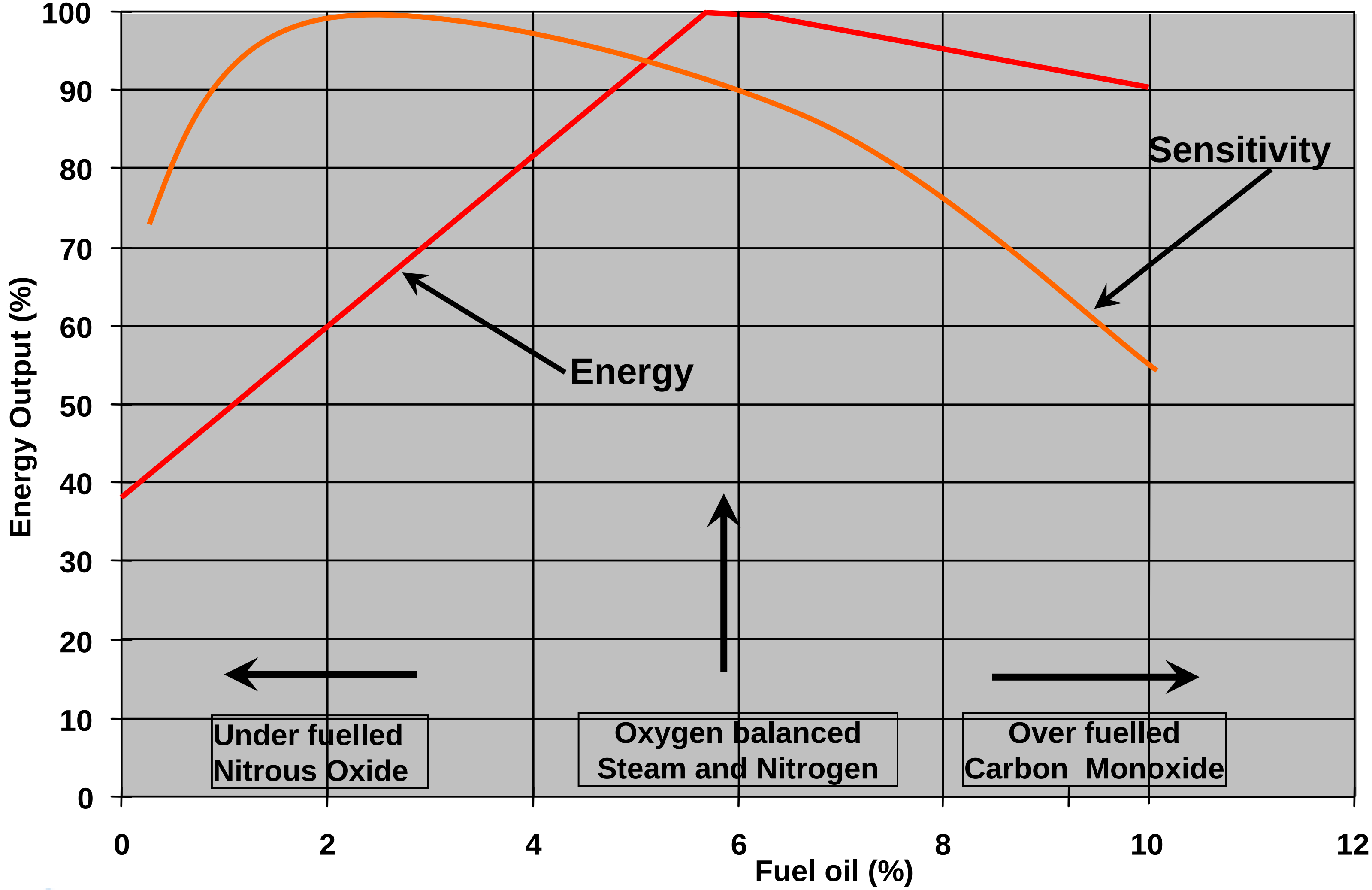
Energy Variation of ANFO



The Product Characteristics are Determined by the Emulsion Formulation

No one characteristic can be considered separate to the others.

The final product formulation is a compromise made to achieve the balance required for the particular application:

- Transport and handling
- Shelf life
- Minimum hole diameter required
- Detonation performance
- Reactive ground

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Why do we use emulsion explosives?

1. **Water resistance**
   - ANFO has no water resistance
   - Emulsion blends can be slept for 2 weeks in wet conditions
2. **Variable density**
   - Different Heavy ANFO blends
   - Gassing sensitivity
3. **Variable energy**
   - Differing percentages of AN and Emulsion
   - Density gradient
   - Differing density
4. **Detonation characteristics**
   - Higher VOD if desirable
   - Heave to shock can be manipulated as needed
5. **Reactive Ground**
   - Inhibited explosives

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Variable Density/Energy

- **Blends with ANFO**
  - ANFO is made from LD porous blasting grade AN prill. Additives include MgO, $Al_2(SO4)_{3,}$, fatty amines, alkyl naphthalene sulphonates etc
  - These additives can have a destabilising effect on the emulsion
  - The % of prill and type of prill affects emulsion stability
  - The chosen emulsion formulation must have suitable stability characteristics for the application
- **Gassing**
  - Addition of gassing chemicals - typically pH modifiers and chemicals that react with the oxidiser components
  - Interaction with the emulsion structure
  - Interaction with the emulsifiers, eg emulsion thinning and thickening

Heavy ANFO Properties

Physical Properties

- Bulk density range is 0.95 - 1.35 g/cm^3
- Sensitivity to initiation is low
- Water resistance increases with emulsion content
- Higher water resistance than ANFO

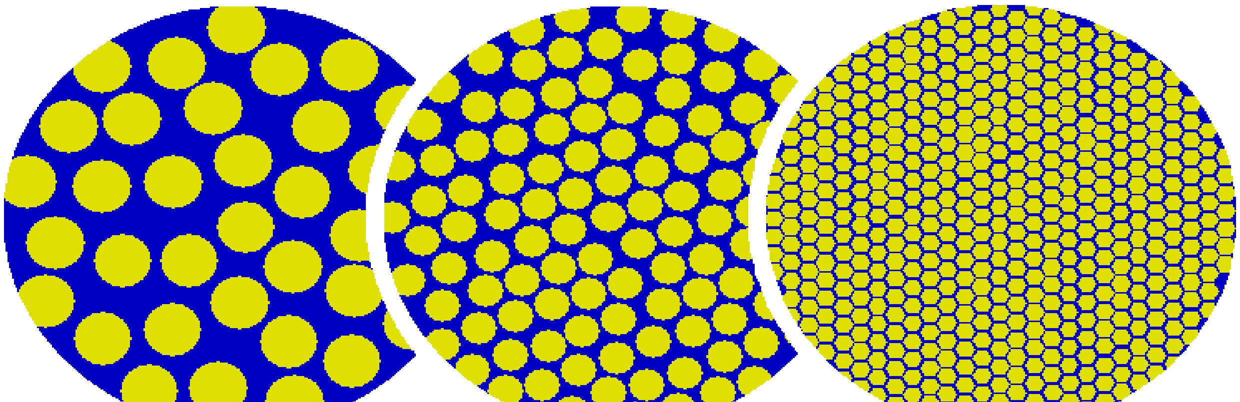
Detonation Properties

- RWS < ANFO*
- RBS > ANFO*
- VoD > ANFO

*Depends on assumptions in energy derivation

The Structure of Homogenized Emulsion

Thin Thicker Homogenized



Magnified Emulsion Cross-Sections

Blue = Fuel
Yellow = Oxidizer Droplets

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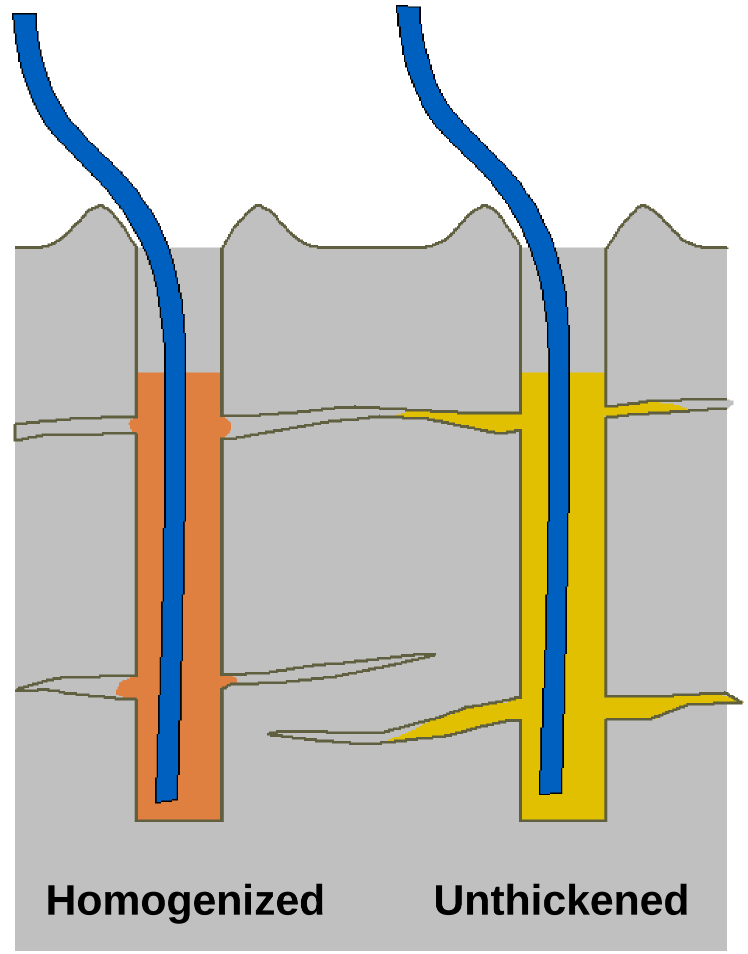
The Benefits of Homogenized Emulsions

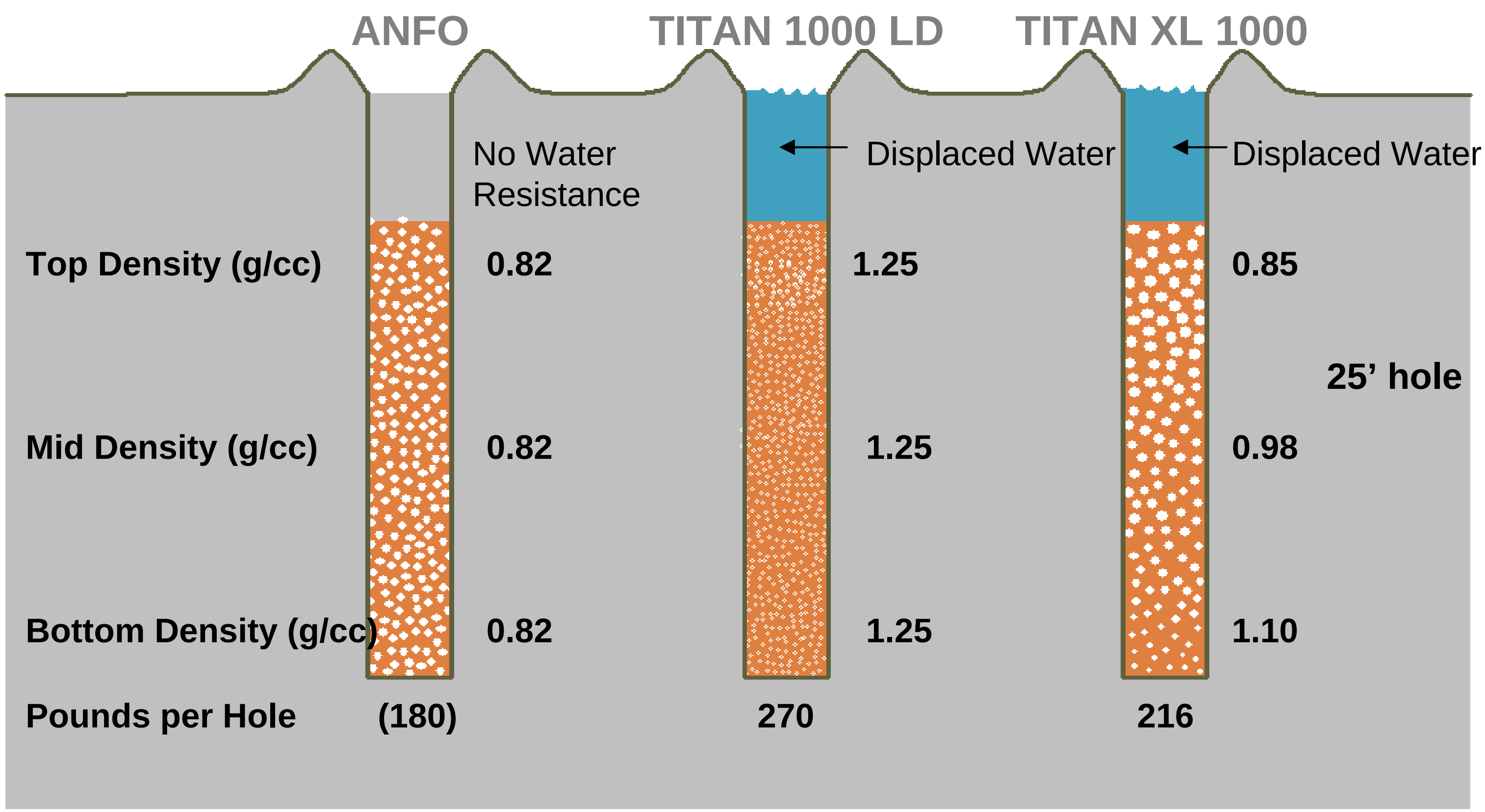
Titan Emulsion is *very* thick and resists flowing into cracks or laminations

- Predictable loading density
- More predictable blast results
- More complete detonation
- Generates less fumes
- Reduces possibility of flyrock and blowout



Bulk Explosives Comparison: Energy / Density Profiles

Density gradient produces higher bulk strength and detonation pressure at the bottom of the hole.



Titan Thickened Emulsion

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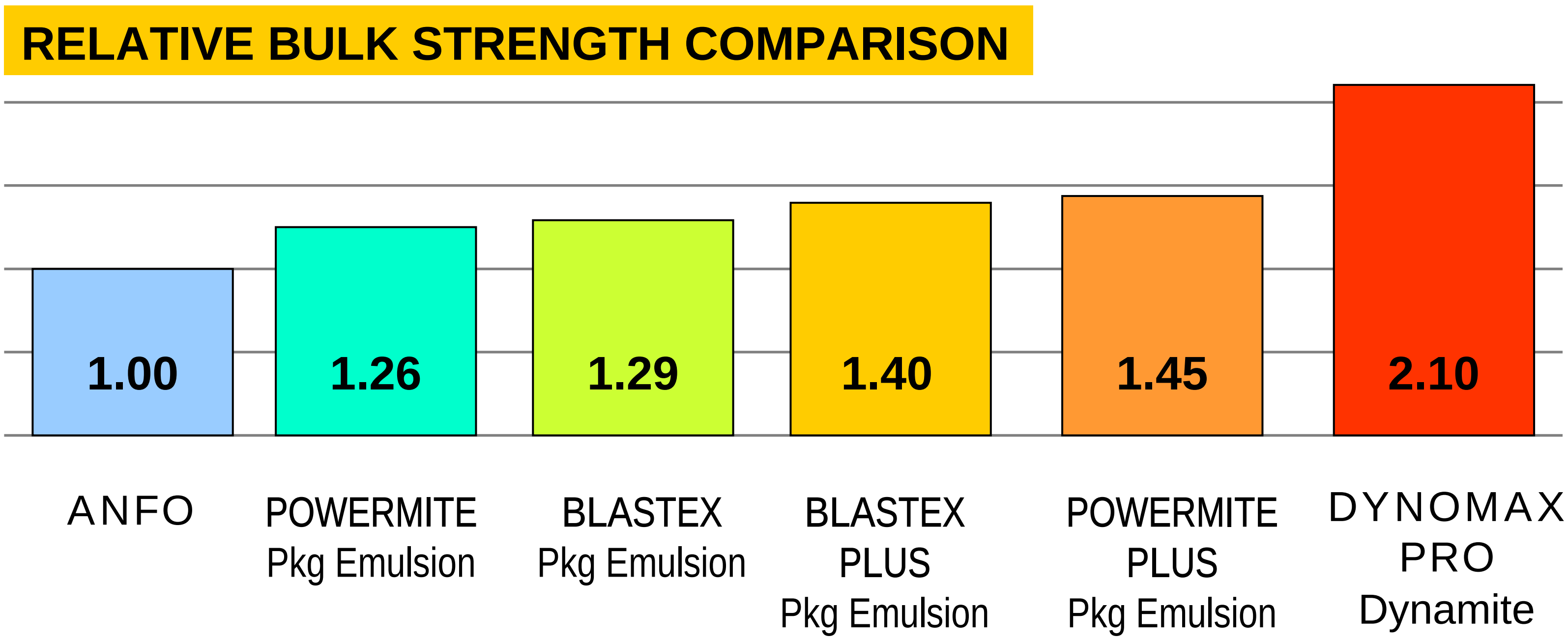
Packaged Products

- Packaged explosives can’t completely fill the blasthole, loss of lbs/ft and drop in Powder Factor
- Increased detonation velocities and density can increase the available energy
- Used effectively in pre-splitting
- Used effectively in customer loading the front row or critical holes

Caution: Don’t let packages free fall into blastholes!

Dynamite

High Bulk Strength - more than other explosives



- **When as much rock-breaking energy as possible must be concentrated in the borehole, dynamite is the answer.**
- **Use dynamite to toe load the column to shear the floor.**
- **Load dynamite and drill smaller holes.**

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Primers

Performance of main explosive column may be strongly influenced by choice of primer

- Run-up zone extends 1 - 3 hole diameters if primer is inefficient or undersized
  - Ensure molecular explosive primer
- Overdrive zone extends 1 - 3 hole diameters if over primed.
- Primer selection should be based on:
  - Composition
  - Shape (diameter that best matches hole diameter)
  - Choice of main explosive
- Additional primers should be used for each 6 m (20 ft) of charge columns
- Recommended minimum detonation pressure for ANFO is 10,000MPa (1,450,000 psi)

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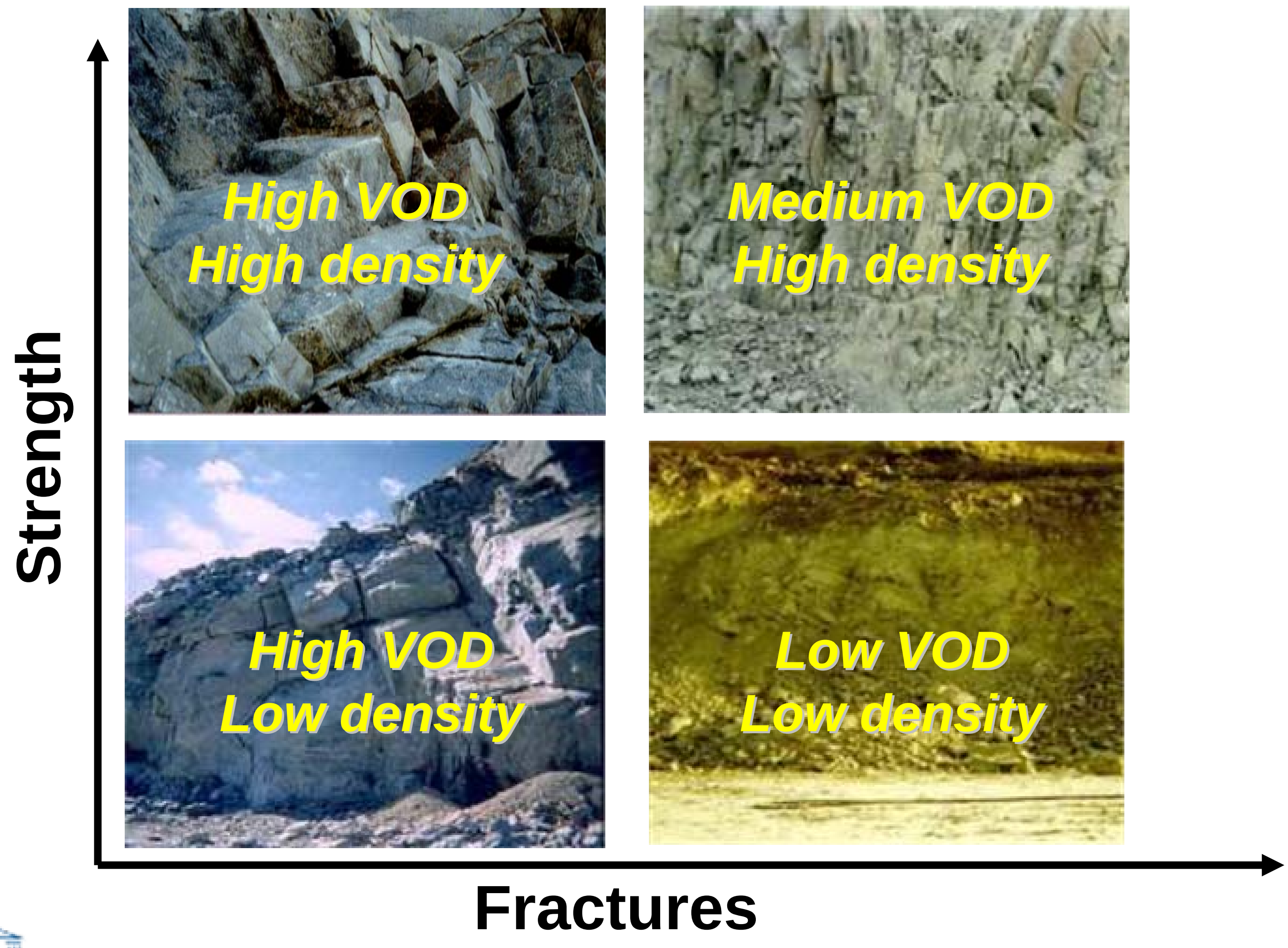
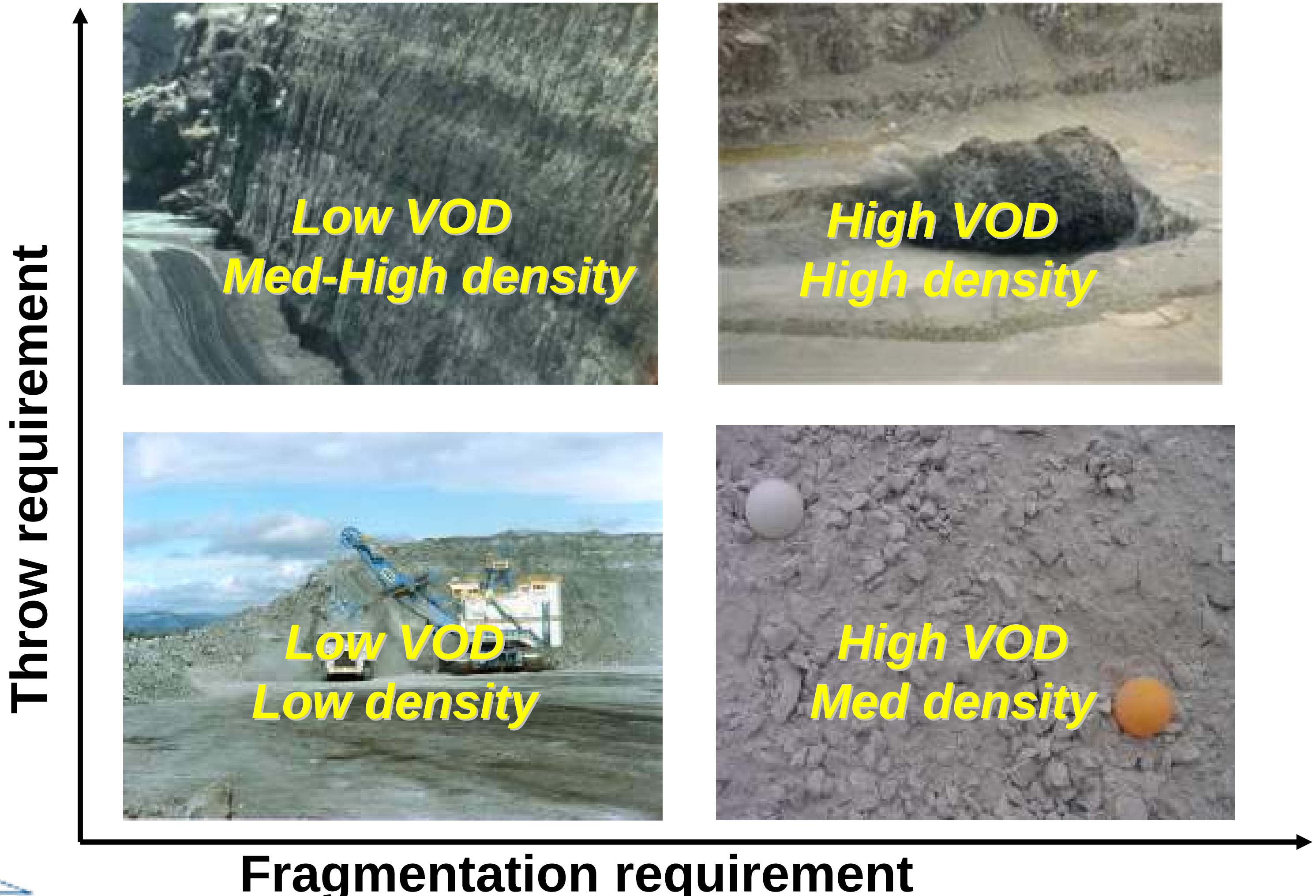
Explosive Selection to Meet Rock Structure and Strength Properties



Explosive Selection to Meet Blast Objectives



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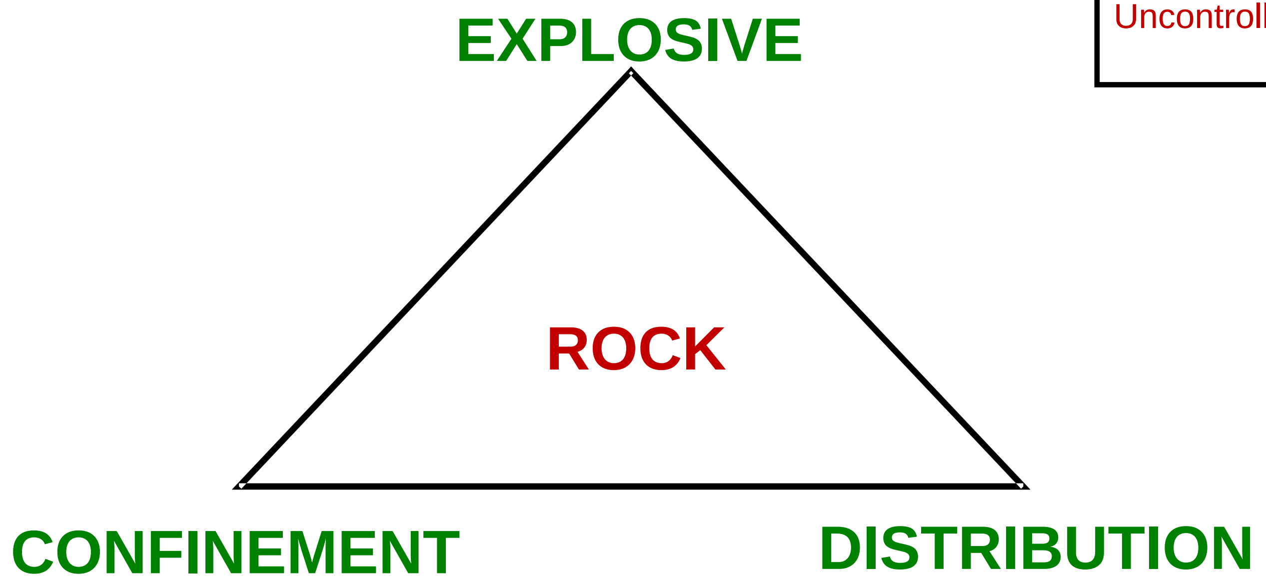
Chemical Crushing - Key Part of the Value Chain

Controllable

Uncontrollable



Design Factors for Drill and Blast

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