Rock Blasting Technique – Mining Engineering Department

HANDOUT

Rock Blasting Technique - I

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Mechanicsm Rock Breakage

Lesson 4

Basic Concept

- During the detonation of an explosive charge inside rock, the condition presented are characterized by two phases of action:
  - 1st. phase. A strength impact is produced by the shock wave linked to the strain energy, during a short period of time.
  - 2nd. phase. The gases produced behid the detonatin front come into action, at high temperature and pressude, carrying the Thermodynamic or Bubble Energy.

Rock Breakage Mechanisms

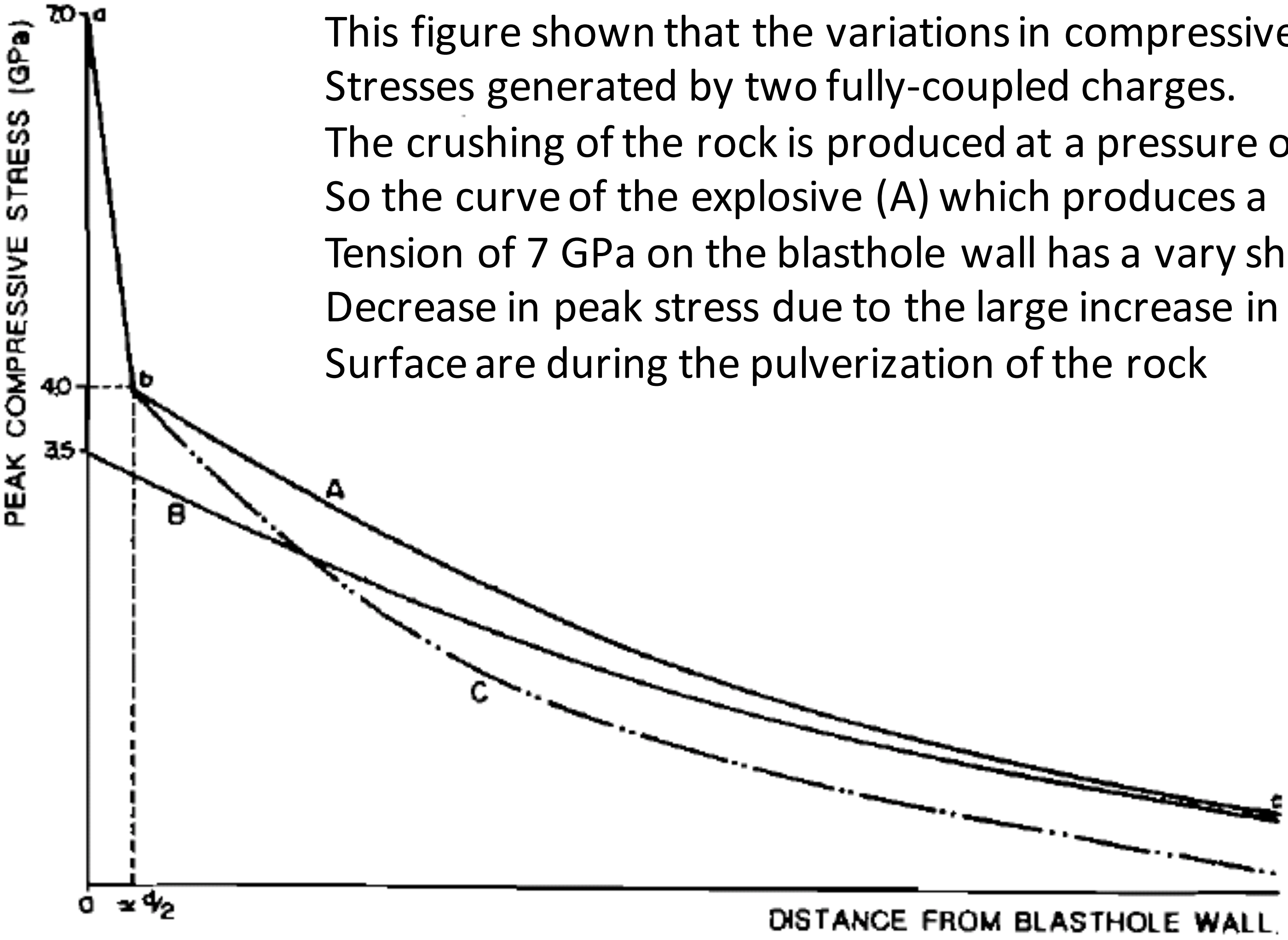
In the fragmentation of rocks with explosives at least eigth breakage mechanisms are involved, with more or less reponsablity, but it all exert influence upon the results of the blastings

1. **Crushing of rock.**
2. **Radial Fracturing.**
3. **Reflection breakage or spalling.**
4. **Gas extention fractures.**
5. **Fracturing by release-of-load.**
6. **Fracturing along boundary of modulus contrast of shear fracturing.**
7. **Breakage by flexion**
8. **Fracturing by in-flight collisins.**

1. Crushing of rock

- In the first instants of detonations, the pressure in front of the strain wave, which expands in cylindrical form reaches values that well exceed the dynamic compressive strength of the rock, provoking the destruction of its intercrystalline and intergranullar structure.
- The thickness of the so called crushed zone increases with detonation pressure of the explosive and wth the coupling between the charge and the blasthole wall. High strength explosives in porous rock it might reach a radius of up to 8 D, but is normally between 2 and 4 D (Duvall and Atchison, 1957).

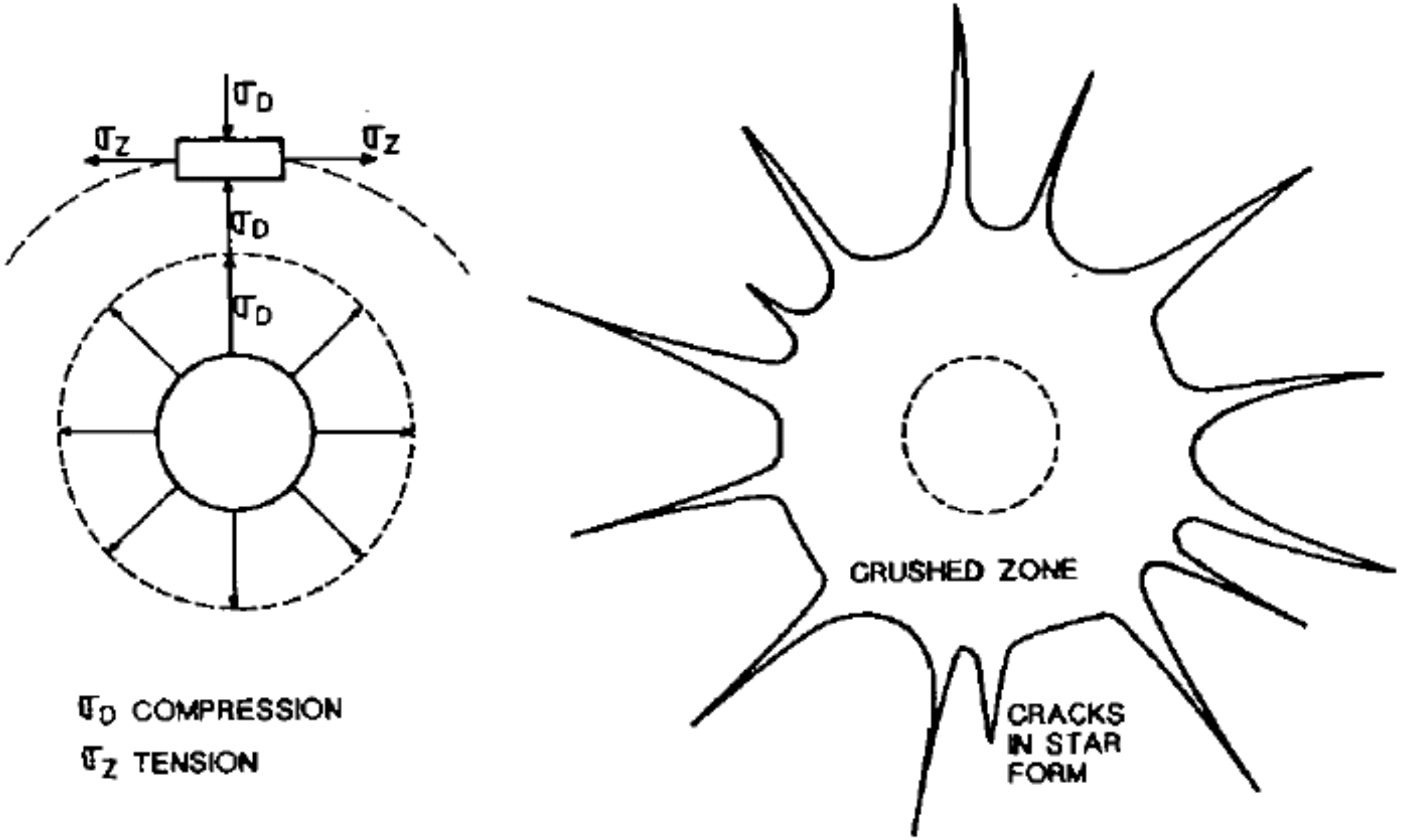
This figure shown that the variations in compressive
Stresses generated by two fully-coupled charges.
The crushing of the rock is produced at a pressure of 4 GPa
So the curve of the explosive (A) which produces a
Tension of 7 GPa on the blasthole wall has a vary sharp
Decrease in peak stress due to the large increase in
Surface are during the pulverization of the rock



Variation of peak compressive stress with
Distance from blasthole wall (Hagan, 1974)

2. Radial fracturing

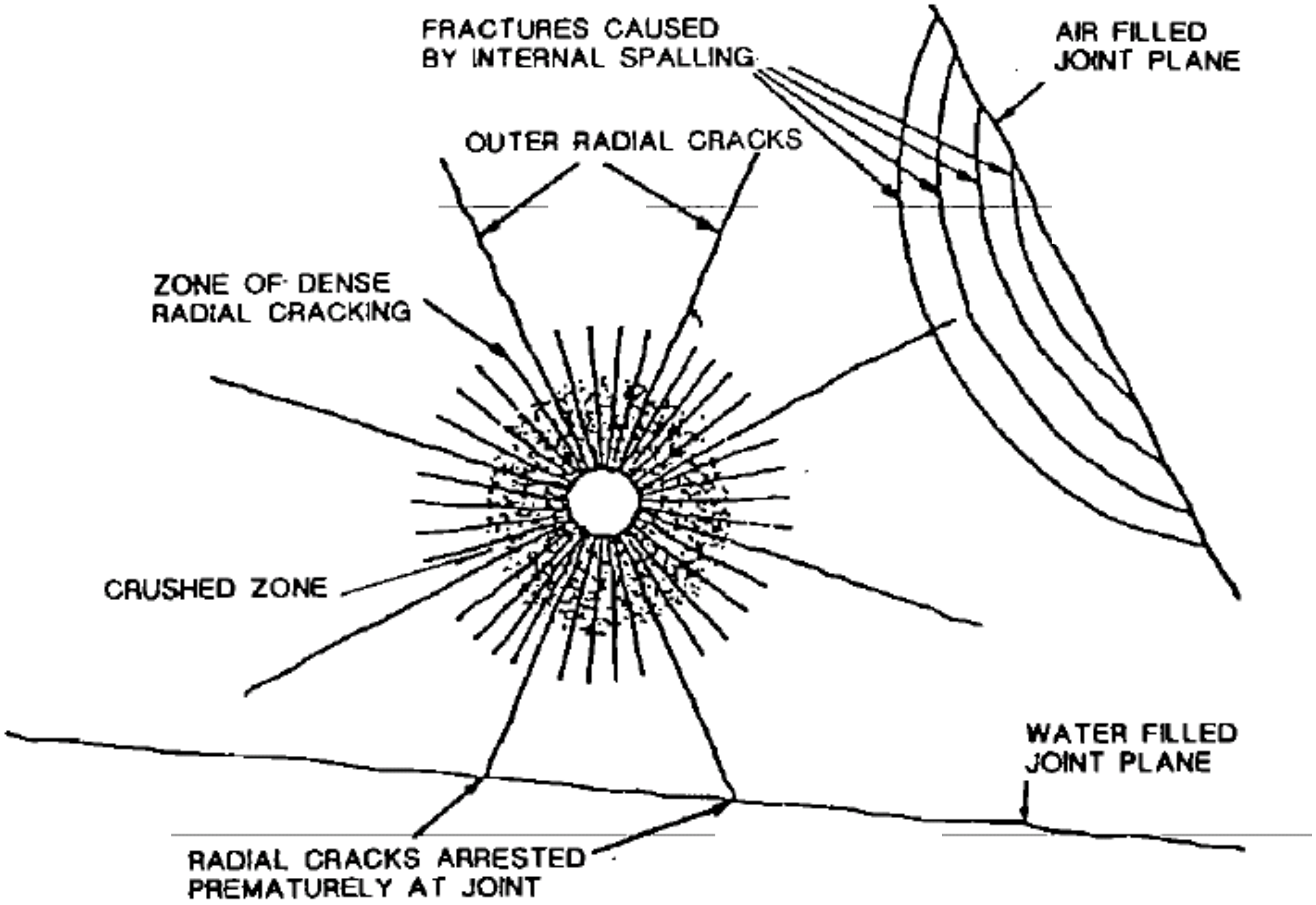
- During propagation of the strain wave, he rock surronding the blasthole is subjected to an intense radial compression which induces tensile components in the tangential planes of the wave front. When the tangential strains exceed the dynamic tensile strength of the rock, the formation of a dense area of radial cracks around the crushed zone that surrounds the blasthole is initiated (see the figure below).
- The number and length of these radial cracks increase with:
  1. The intensity of the strain wave on the lasthole wall or on the exterior limit of the crushed zone, and
  2. The decrease in dyanmic tensile strength of the rock and teh attenuation of the strain energy.



Radial Crack

Radial fracturing

- When the rock has natural fractures, the extension of the cracks is closely related to these. If the explosive coloumns are intersected lengthwise by a pre-existing crack, these will open with the effect of the strain wave and the development of radial cracks in other directions will be limited. The natural fractures that are parallel to blastholes, but at some distance from them, will interrupt the propogation of the radial cracks.



Radial fracturing and breakage through reflection of the strain wave.

3. Reflection Breakage or Spalling

- When the strain wave reaches a free surface two waves are generated, a tensile wave and a shear wave. This occur when the radial cracks have not propogated farther than one third the distance between the charge and free face. Although the relative magnitud of the energies associated with the two waves depends upon the incident angle of the compressive strain wavem the fracturing is usually caused by the refalected tensile wave. If the tensile wave is strong enough to exceed the dynamic strangth of the rock, the phenomenon known as saplling will come about, back toward the interionof the rock. The tensile strengths of the rock reach values that are between 5 and 15% of the compressive strengths.

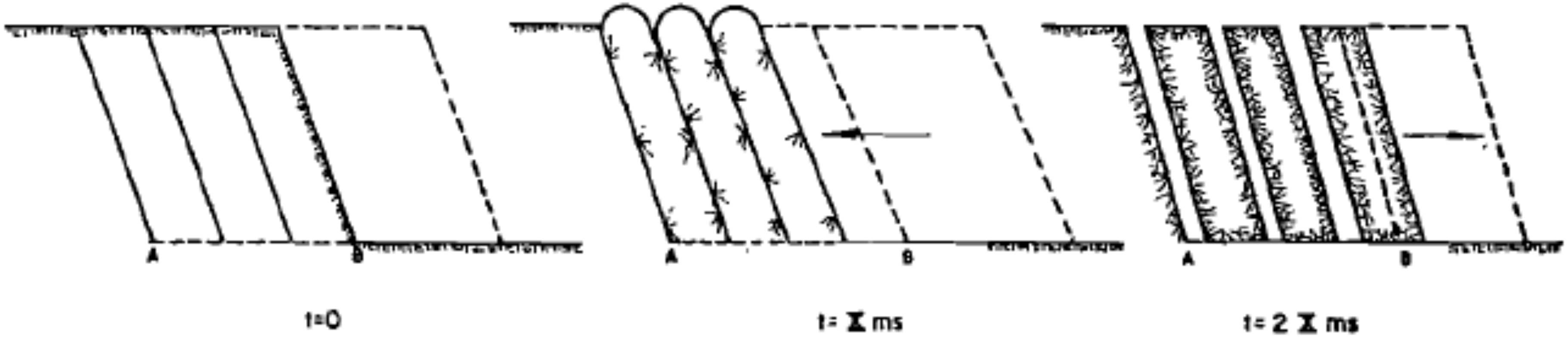
4. Gas Extension Fractures

- After the strain wave passes, the pressure of the gases cause a quasi-static stress field around the blasthole. During or after the formation of radial cracks by the tangential tensile component of the wave, the gases start to expand and penetrate into the fractures. The radial cracks are prolonged under the influence of the stress concentrations at their tips. The number and length of the opened and developed cracks strongly depend upon the pressure of the gases, and a premature escape of these due to insufficient stemming or by the presence of a plane of weakness in the free face could lead to a lower performance of the explosive energy.

5. Fracturing by release-of-load

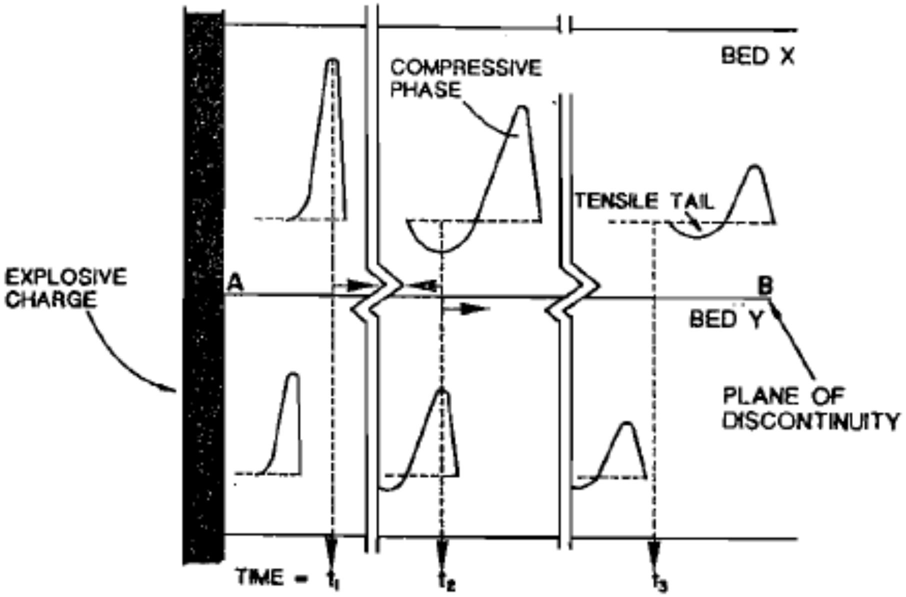
- Before the strain wave reaches the free face, the total energy transferred to the rock by initial cornpression varies between 60 and 70% of the blast energy (Cook et al. 1966).
- After the compressive wave has passed, a state of quasi-static equilibrium is produced, followed by a subsequent fall of pressure in the blasthole as the gases escape through the stemming, through the radial cracks and with rock displacement.
- The stored Stress Energy is rapidly released, generating an initiation of tensile and shear fractures in the rock mass. This affects a large volume of rock, not only in front of the blastholes but behind the line of the blast cut as well, having registered damages in up to dozens of meters away, see Fig below.

Separation of layers of compresible medium by release-of-load



6. Fracturing along boundaries of modulus contrast of shear fracturing

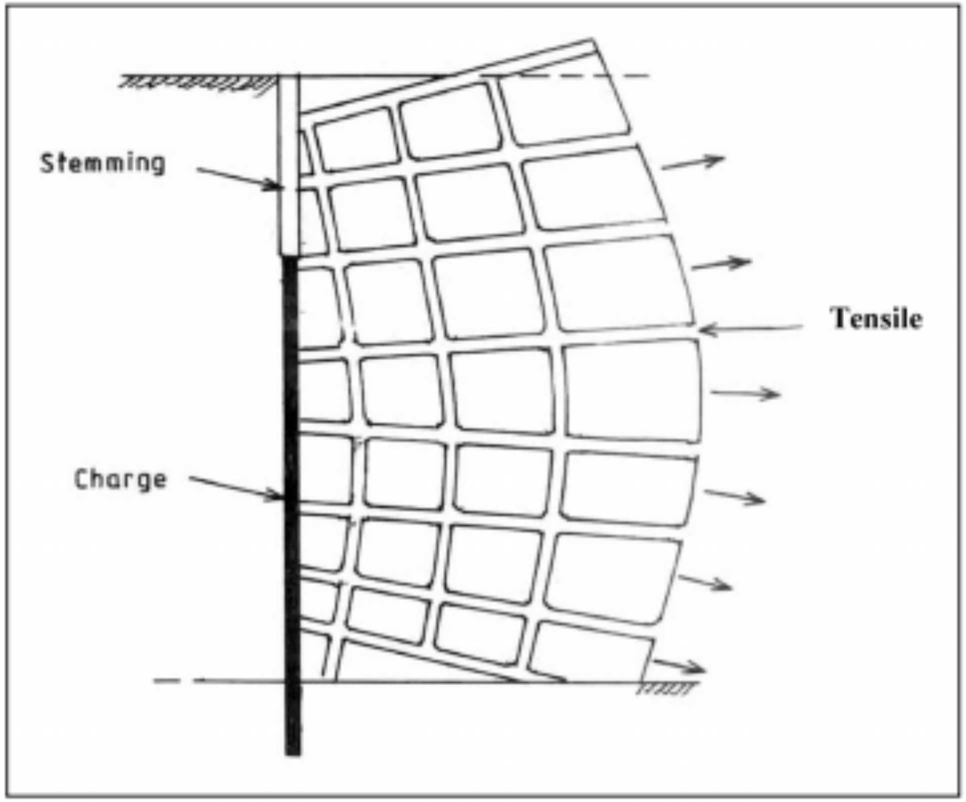
- In sedimentary rock formations when the bedding planes, joints etc., have different elasticity modulus or geomechanic parameters, breakage is produced in the separation planes when the strain wave passes through because of the strain differential in these points..



Shear Fracturing (Hagan

7. Breakage by flexion

- During and after the mechanisms of radial fracturing and spalling, the pressure applied by the explosion gases upon the material in front of the explosive column makes the rock act like a beam embedded in the bottom of the blasthole in the stemming area, producing the deformation and fracturing of the Same buy the phenomena of flexion.



Mechanism of breakage by flexion, after Ouchterlony (1995)

8. Fracture by in-flight collisions

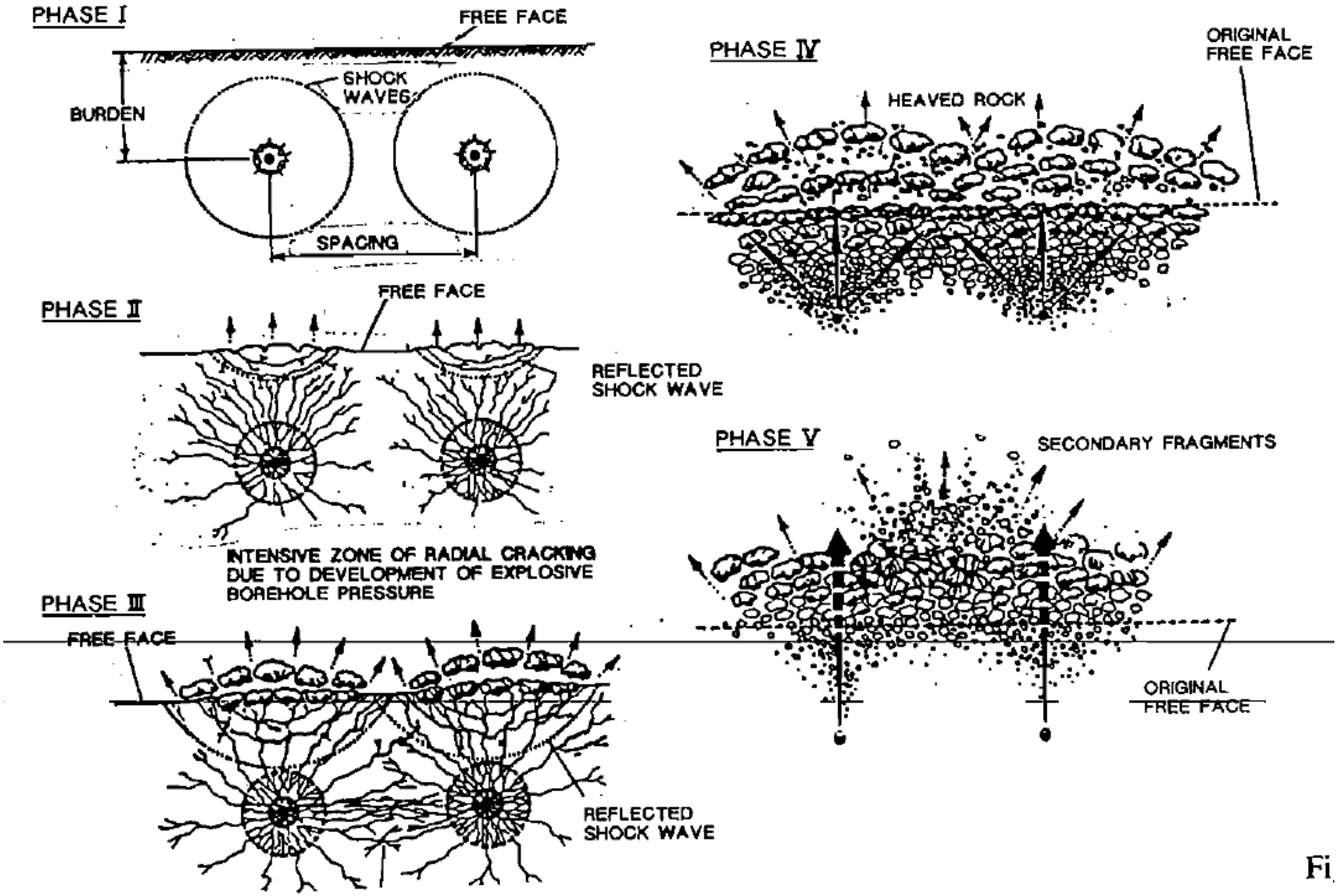
- The rock fragments created by the previous mechanisms and accelerated by the gases are projected towards the free face, colliding with each other and thereby producing additional fragmentation which has been demonstrated by ultra-speed photographs (Hino, 1959; Petkof, 1969).

Bubble Energy

- **The performance of explosives upon the rock is, therefore, a group of elemental actions which perform simultaneously** in a few mili seconds, associated with the effects of the strain wave which transports the ***Stress Energy,*** and with the effects of the explosion gases or ***Bubble Energy.***
- The estimates carried out by Hagan **(1977)** have demonstrated that only a **15%** of the total energy generated in the blasting is used as a working tool in the mechanisms of rock fragmentation and displacement.

Bubble Energy

- Rascheff and Goemans (1977) have established a model that theoretically distributes the energy, as represented in next Figure from tests made upon cubic blocks of rock placed underwater in swimming pools. These investigators assure that approximately **53%** of the explosive energy is associated with the strain wave. This value depends upon the conditions of the experiment and very different results can be found that go from **5** to **50%** of the total energy, depending upon the various types of rock that are to be fragmented the explosives used.
- Therefore, in hard rock the Strain Energy of a breaking explosive is more important in fragmentation than the Bubble Energy, and the contrary is true for soft, porous or fissured rocks and in low density explosives.


PHASE I
FREE FACE
SHOCK WAVES
BURDEN
SPACING
PHASE II
FREE FACE
REFLECTED SHOCK WAVE
INTENSIVE ZONE OF RADIAL CRACKING DUE TO DEVELOPMENT OF EXPLOSIVE BOREHOLE PRESSURE
PHASE III
FREE FACE
REFLECTED SHOCK WAVE
PHASE IV
ORIGINAL FREE FACE
HEAVED ROCK
PHASE V
SECONDARY FRAGMENTS
ORIGINAL FREE FACE

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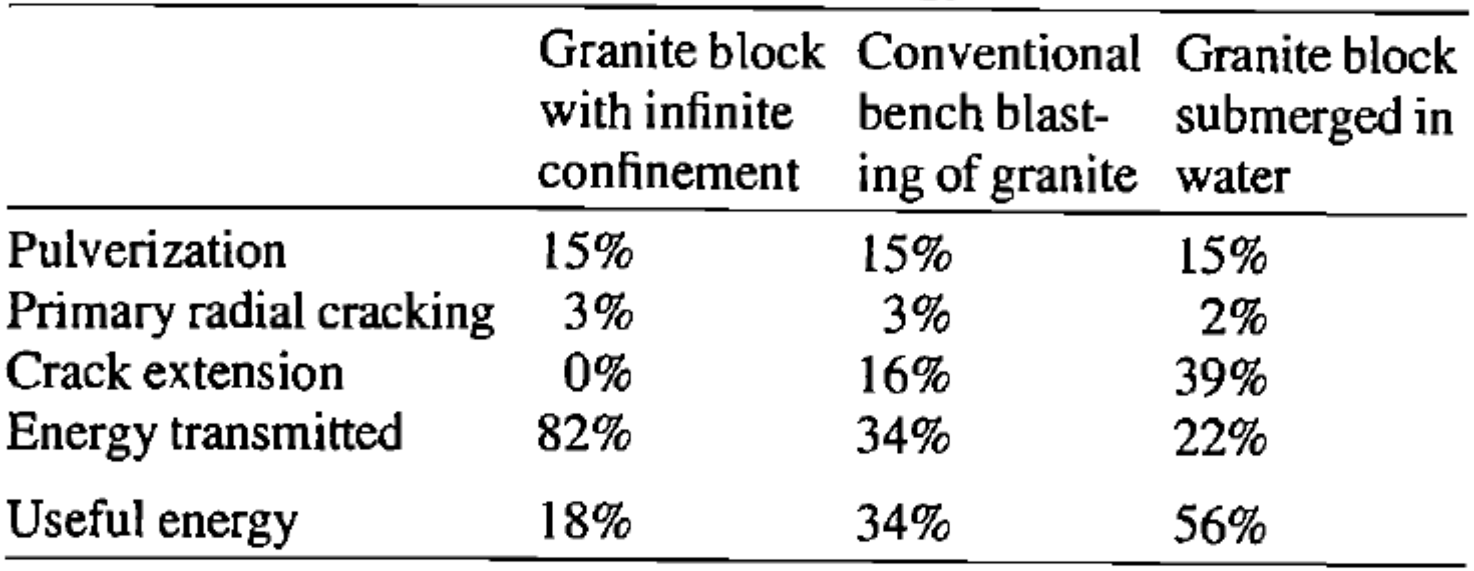
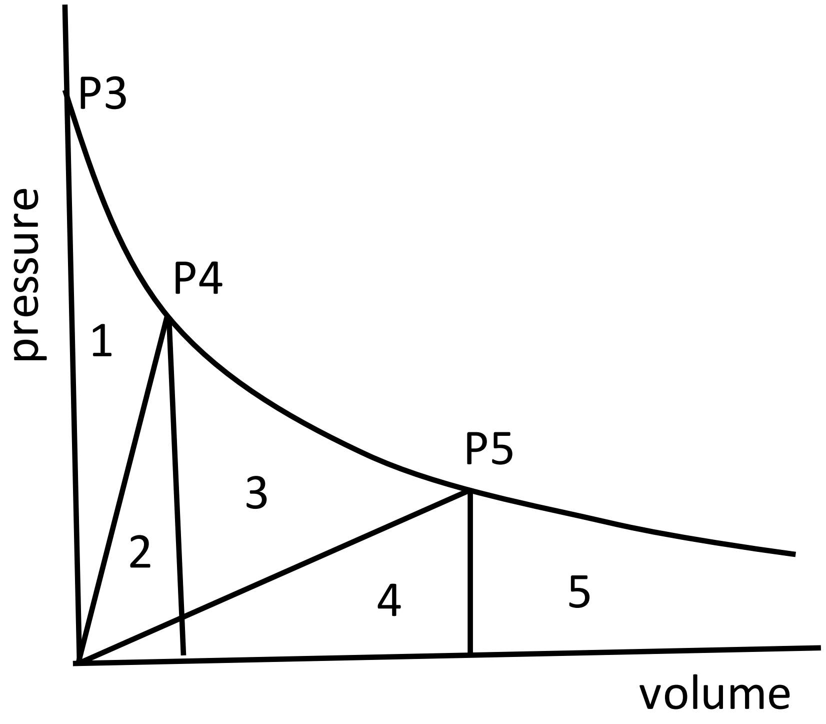
From the tests carred out by Rascheff and Geomans, Table summerizes the energy distribution of the strain wave.



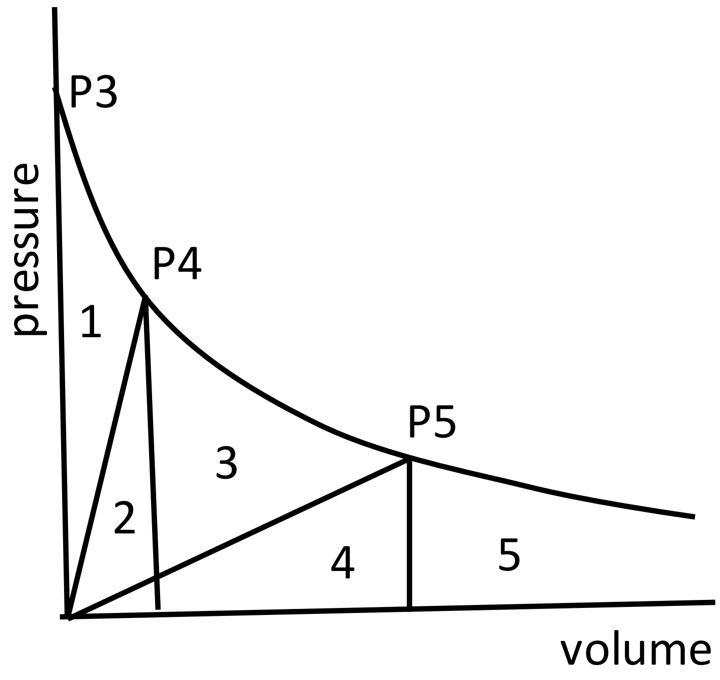
	Granite block with infinite confinement	Conventional bench blasting of granite	Granite block submerged in water
Pulverization	15%	15%	15%
Primary radial cracking	3%	3%	2%
Crack extension	0%	16%	39%
Energy transmitted	82%	34%	22%
Useful energy	18%	34%	56%

Explosive Rock Interaction

- Lowends used a simplified model of ratio explosive rock interaction to describe the partition of explosive energy in the process of rock blasting. The energy is partitioned into different zones hat are related to the ratio pressure volume expansion of the gases during the different phases of blasting. An illustration of this partition of energy is given in Figure.

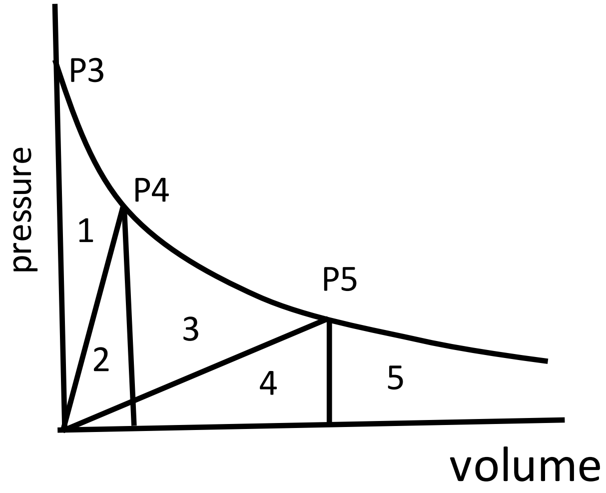


The energies associated with the different zones given in the figure are, as follows

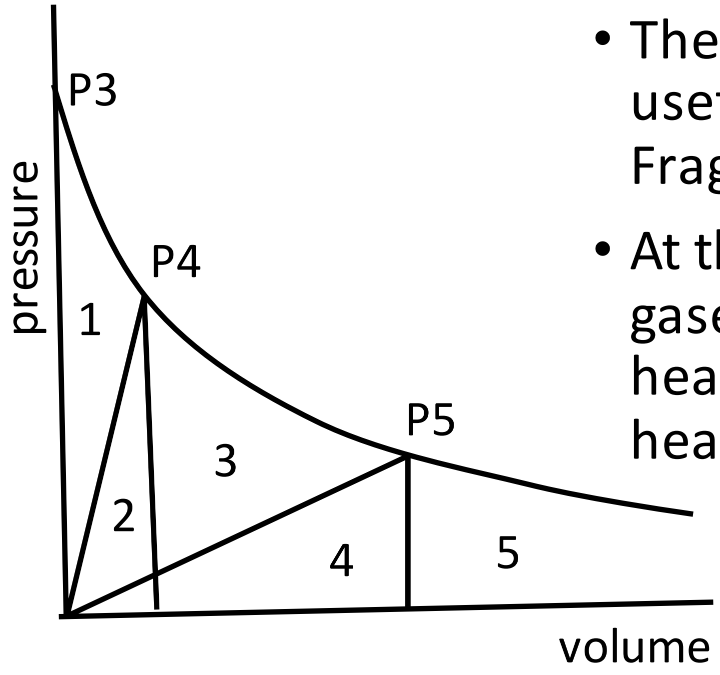


- When the explosive detonates in the blasthole, the high pressure gases at the initial or explosion state P3 send a shock wave into the rock. The strains from this shock near the blasthole are greater than the dynamic compressive and shear strength of the rock. They cause varying amounts of rock compression and crushing in the surrounding area of the blasthole depending upon the strength and stiffness of the rock. With rock compression and crushing the volume of the blasthole increases and the pressure decreases until the strain in ihe rock balances the pressure.

- This is shown P4 on the pressure/volume curve of Figure and is called blasthole equilibrium state. During the expansion, the work being done by the explosive is called brissance energy and consists of the strain energy stored in the rock (Zone 2) and the kinetic energy of the shock wave (Zone 1). The kinetic shock energy is essentially lost as useful work during the blasting process and appears as crushed rock surrounding the blasthole and as seismic waves propagated into the ground.



- The strains in the rock coming from the residual blasthole pressure P4 cause fracture. The explosion product gases enter at least the cracks existing between the hole and the free face, resulting in fragmentation and possibly contributing to the heave. When the gases reach the free face through the burden, the process ends more or less abruptly. The pressure of the gases at escape is shown at P5 in Figure. During escape, the burden is compressive pressed by the gas in the cracks with a strain energy stored in the rock (Zone 4). This energy has little influence on fragmentation and heave.



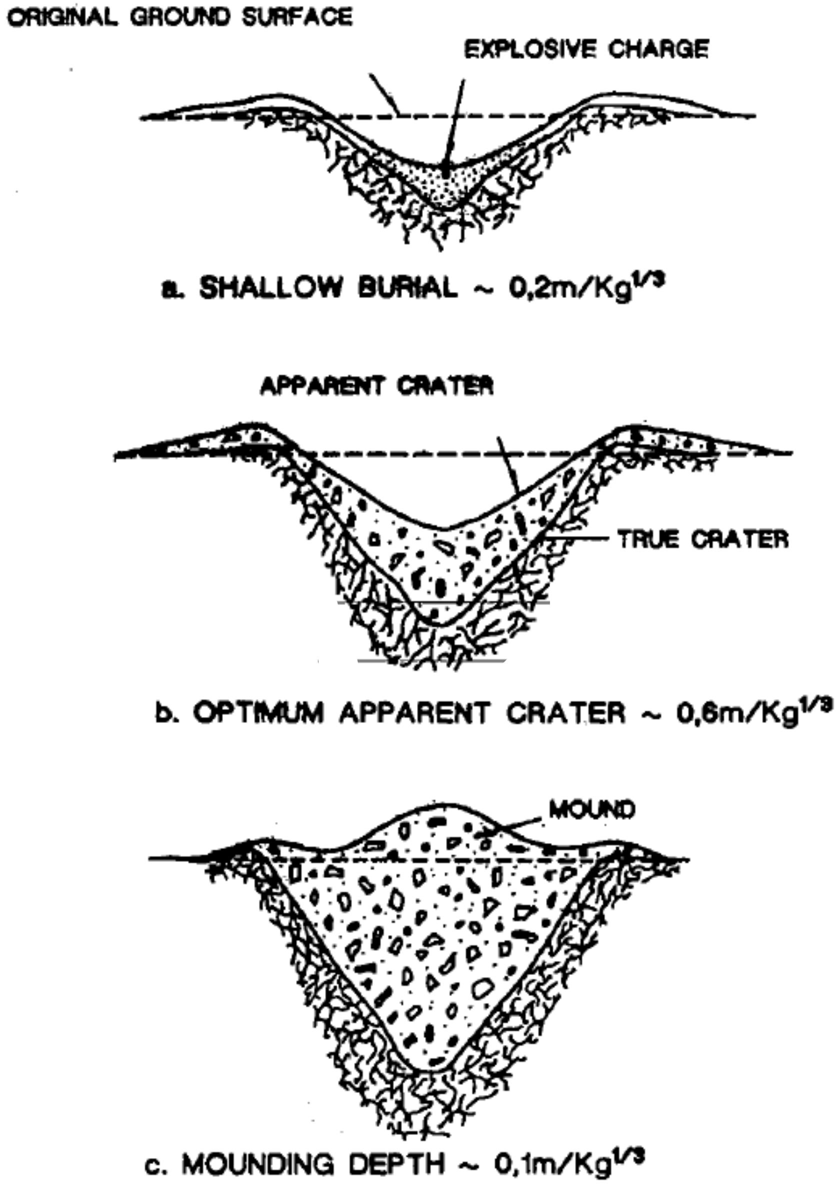
- The energy from Zones 2 and 3 is the most useful in rock blasting and is called Fragmentation Energy.
- At the time of escape, some of the energy in the gases (Zone 5) moves the burden and represents heave energy. The rest of this energy is lost as heat and noise in the escaping gases.

Zone	Energy
1	Kinetic component of shock energy
2	Strain component of shock energy
1 + 2	Brissance energy
3 + 4	Energy released during crack propagation
2 + 3	Fragmentation energy
4	Strain energy in burden at time gases escape
1 + 2 + 3 + 4	Blast energy
5	Heave energy
1 + 2 + 3 + 4 + 5	Total available energy or absolute strength value

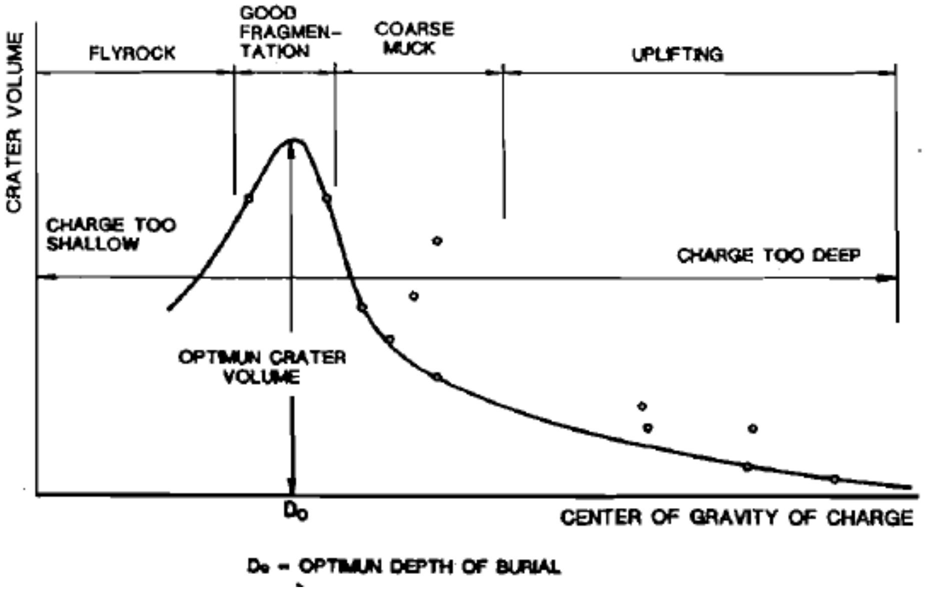
Crater Blasting

- The concept and development of crater blasting attributed to C.W. Livingston (1956), opened a new school of thought for better understanding of the phenomenon of blastings and the characterization of the explosives.
- Bauer (1961), Grant (1964) and Lang (1976) among others, widened the field of application of this theory, converting it into a basic tool for the study of surface as well as underground blastings.
- A crater blast is that which is carried out with concentrated sphencal or cubic charges and with good approximation using relatively short cylinder charges that are detonated inside the rock mass to be fragmented.

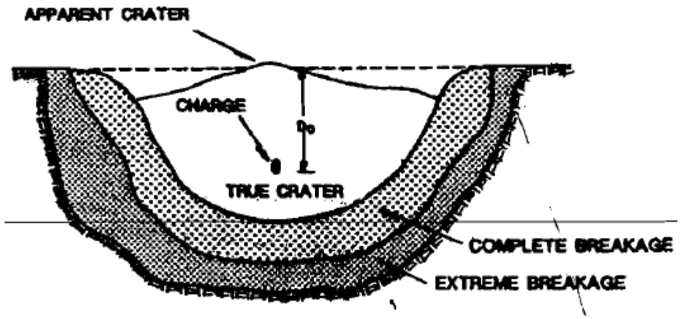
- In Figure, the influence of the energy transmitted by the explosive to the rock, depending upon the depth of the charge and the volume of material affected by the blast. When the charge has a very shallow burial (a) most of the energy is transmitted to the atmosphere in form of airblast, up to an excessive depth (c) where all the energy is applied upon the rock, fragmenting it and producing a high intensity vibration. Between the two situations, there will be one that produces a larger crater.



Effects of increasing depth of burial on crater shapes



After each test, the volume of the crater will be measured, and afterwards, with all information in hand, the volume-depth curve will be established.



The mound is subdivided into the Zone of complete fragmentation and that of extreme or tensile fragmentation. In blastings with inverted faces, ths crater sizes are influenced by the effect of gravity and the structural charactenstics of the rock, forming elongated, elliptic shaped cavities which correspond to the extreme rupture or stressed zones.