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**Controlled Fracture Method and Apparatus for
Breaking Hard Compact Rock and Concrete Materials****BACKGROUND OF THE INVENTION**

Since the invention of dynamite in 1866, explosive blasting has been the primary technique utilized for the excavation of hard rock. Despite many improvements in rock excavation technology over the years, methods suitable for the continuous excavation of hard rock do not yet exist, whether for mining or civil construction. Conventional drill and blast remains the only technique which may be utilized to excavate the harder rocks, such as granite and gneiss, with reasonable efficiency. Numerous mechanical and water jet assisted systems have been developed for the efficient excavation of softer, typically sedimentary rocks. Recent improvements in tunnel boring machines have allowed these machines to cut relatively hard rock up to 300 MPa in compressive strength, but cutter wear remains a serious problem. These systems are not able to effectively excavate the harder rocks, however. Also the TBM type of machines are limited in their mobility and in their ability to cut irregularly shaped openings.

Conventional drill and blast, while being able to excavate the hardest of rocks at acceptable efficiencies, is limited, in that the technique must be applied in a cyclic drill, blast and muck fashion, resulting in the inefficient and often interfering use of the machines required for each cycle. Conventional drill and blast is also limited, in that considerable damage is done to the rock left around the structure being excavated, with this residual damage often requiring additional and expensive ground support. For commercial mining operations, the conventional drill and blast method is limited, in that all of the rock excavated from a mine heading in a single drill and blast round is so jumbled and mixed that all of the rock must be removed from the mine, crushed, milled and processed for ore removal. Numerous mining operations involve the excavation of vein-

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type deposits, where the ore-bearing rock is restricted to a small section of the excavation face. A method whereby the ore-bearing rock could be selectively mined and transported to the surface for milling and extraction, with the remaining barren rock being left underground, would significantly improve the economics of many mining operations. For civil construction, the conventional drill and blast method is often limited, in that the large air blast and ground shock associated with each blast preclude the method being utilized in urban construction. Also the residual damage caused to the remaining rock often compromises the mechanical integrity of the structure, requiring additional and expensive ground support.

Rapid Excavation Techniques

Due to the inherent limitations of conventional drill and blast methods as discussed above, considerable research has been devoted over the past 20 years to the development of alternative rapid excavation techniques suitable for hard rock. The approaches which have been considered during these two decades of research have ranged from water-jet impact (Young, 1977) through high-velocity projectile impact (Lundquist, 1974), to small-charge blasting (Lundquist and Peterson, 1983). Both continuous (Zink et al., 1983) and pulsed water-jet impact techniques (Young, 1977; Young, 1985) have been investigated in considerable detail. In general, the continuous water-jet techniques cannot generate water-jet pressures high enough to efficiently cut the harder rocks. While the pulsed water-jet impact techniques can cut the hardest of rocks, the energy efficiency of these techniques and the mechanical complexity of the pulse-jet generating devices has hindered the commercial development of the techniques. Rapid excavation techniques based upon projectile impact have included consideration of a very small projectile (pellet) impact (Singh, 1960), very large projectile impact (where the projectiles might be launched with conventional 104 mm military cannons (Lundquist, 1974),

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and have even included consideration of explosive projectiles which would increase the rock damage by their detonation upon impact (Louie, 1973). The poor efficiencies of the small pellet impact approaches have precluded their development, while the very large air blast problems inherent in the large projectile and explosive pellet approaches have hindered their commercial development.

Small-Charge Blasting

Due to the relative efficiency characteristic of conventional drill and blast techniques, considerable research has been devoted to the scaling down and automation of drill and blast approaches so they might be applied on a small-charge continuous drill and blast basis. Most notable among these approaches is the Rapidex spiral drill and blast system, which received considerable research consideration during the 1970's (Lundquist and Peterson, 1983). Interest in the further development in continuous drill and blast techniques has been limited due to the relatively large explosive loadings that are still required in the scale-down systems, and the consequent requirement that considerable effort would need to be devoted to protecting both machines and personnel operating at or near the excavation face. The explosive quantities in these continuous drill and blast approaches often remained high because conventional charge loadings were employed and several shot holes were typically required to be detonated nearly simultaneously for proper operation of the technique (Clark et al., 1979).

Fracture Control Blasting

A third approach to the development of more efficient excavation techniques involved the consideration of methods for applying controlled fracture techniques to the rock breaking process. As less than one percent of the total energy expended in conventional drill and blast is utilized to develop the desired tensile fractures within the rock, it is quite attractive to investigate methods by which the energy required for rock fracture may be much more

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efficiently applied to the fracturing process. Controlled fracturing techniques recently developed by the University of Maryland (Dally and Fourney, 1977), the Swedish Detonic Research Foundation (Bjarnholt et al., 1983) and elsewhere (Young and Fourney, 1983) have shown that, with proper fracture initiation and control, the quantity of explosive charges required to achieve a given desired fracturing can be significantly reduced. Other research into the controlled fracture of rock has resulted in the development of both static and dynamic techniques, wherein the geometry of the breakage process might significantly reduce the energy requirements. In general, these approaches involve methods whereby the primary rock breaking fractures could be developed roughly parallel to a free face, resulting in less energy being required for fracture development. One static method based upon this approach involves a mechanical device which could act in a relatively shallow borehole and by means of grippers, could pull (spall) the rock toward the free face from which the hole was drilled (Cooper et al., 1980, Anderson and Swanson, 1982). A dynamic approach employing a comparable geometry involved the firing of steel pistons into shallow water-filled holes, such that the rapid pressurization of the hole would result in the initiation and propagation of a fracture from the stress concentration occurring at the sharp corner at the hole bottom (Denisart et al., 1976). A fracture so initiated would tend to propagate out from the hole and parallel to the free face from which the hole was drilled. While this approach yielded very attractive rock excavation efficiencies, difficulties with the rapid loss of the pressurization liquid when fracturing other than from the hole bottom occurred, and with the frequent jamming of the steel pistons in incompletely broken holes, precluded the further commercial development of the technique. In order to avoid the piston jamming problem, a method utilizing high pressure, high velocity slugs of water fired into shallow holes has also been proposed (Lavon,

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1980).

Based upon the excellent rock breakage efficiencies which could be obtained with fracture control techniques applied to specialized rock breakage geometries, and the premise that better methods for pressurizing and propagating these fractures could be developed, small research effort in 1984 demonstrated that small explosive or propellant charges could be utilized to effectively apply controlled fracture techniques to unique rock breaking geometries (Young and Barker, 1984). The primary geometry considered is illustrated in Figure 1 and was based in part upon the geometry proposed by Denisart et al. (1976). As indicated in Figure 1, this fracturing is predicated upon the initiation and propagation of a fracture from the bottom of a shallow and rapidly pressurized borehole. Such a fracture could be expected to propagate initially down into the rock and to then turn towards the free surface as surface effects became important, thus resulting in the removal of a large volume of rock. The residual cone left on the rock face by the initial penetration of the fracture into the rock provides the basis for the name (penetrating cone fracture, or PCF) given to this type of fracturing. In contrast with the earlier work of Denisart et al., later research efforts considered the possibilities for initiating and propagating cone fractures from shallow boreholes with small propellant and decoupled explosive charges (Young and Barker, 1984).

SUMMARY OF THE INVENTION

The intention of the present invention is to disclose a continuous drill-and-blast rapid excavation system (apparatus and method) based upon the penetrating cone fracture (PCF) approach.

The excavation of hard rock for both mining and civil construction applications is usually accomplished with the traditional drill and blast method. Due to the cyclic nature of drill and blast operations (drill, blast, ventilate and

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muck), excavation rates are limited and equipment utilization is low. A small-charge rapid excavation system employing a novel fracture initiation and propagation technique has been demonstrated to be capable of excavating the hardest of rocks at efficiencies (energy per unit volume of rock removed) four to ten times greater than attainable with conventional drill and blast. Significant enhancements to the concept include the use of propellant rather than explosive charges, and the design of devices for containing the charges and effectively sealing the shot holes.

It is the object of this invention to provide an improved rapid excavation method and apparatus. A machine is disclosed integrating drilling, small-charge blasting and mucking that remains at the excavating face during continuous operations. An excavation method using the machine involves: optimizing rock breakage with the penetrating cone fracture technique; establishing optimum hole patterns and cone fracture interactions through spacing and placement; optimizing borehole sealing by incorporating established stemming parameters and new sealing techniques; and optimizing continuous drilling, blasting and mucking operations by incorporating established rock breakage parameters, drilling parameters, and propellant (explosive) charge parameters. Furthermore, the machine could incorporate robotic control into a smart system capable of optimizing shot hole placement and geometry and charge characteristics for specific rock conditions.

The small-charge rapid excavation system would be attractive for mining and civil construction operations where sensitive structures, equipment and personnel would be in close proximity to the excavation face. The small-charge rapid excavation system would be attractive in selective mining operations where the ore rock could be fragmented and processed separately from the barren country rock. The barren rock could then be kept underground and eliminated from the traditional hauling and milling operations.

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Hard compact materials, such as rock, concrete, et cetera, are broken by igniting an appropriately designed explosive or propellant charge placed within the hole or carried in a special charge-containing device with a short barrel which is inserted and sealed into a pre-drilled hole of particular geometry. One or more approximately cylindrical holes are drilled into the material to be broken by conventional drilling means, such as used in the mining and construction industries.

The holes have a relatively short depth to diameter ratio, being in the range of about 2.5 to 1 to 10 to 1, and preferably about 3 to 1 to 4 to 1. The holes may be drilled with sharp hole bottoms so as to enhance fracture initiation at the hole bottoms, or may be notched at the hole bottom or at other locations so as to provide for preferred fracture initiation. Microfracturing from percussive drilling is extremely beneficial to the process by providing fracture initiating sites.

The explosive or propellant charges may be any of several commercially available explosives or propellants, including standard military and commercial rifle powders and various recently developed liquid propellants.

The propellant charges, whether solid or liquid, may be placed and ignited within a charge-containing device, which includes a short barrel inserted into the holes drilled into the material to be broken. The barrel of this device may be further sealed into the holes by means of a helical shim sealing method or by having a slight shoulder on the barrel pressed against a slight step on the hole wall. The charge-containing device is prevented from being accelerated out of the hole by means of a heavy steel bar or comparable structure held against the rearward end of the charge-containing device.

With the controlled pressurization of the hole, realized with the proper combinations of explosive and/or propellant charge, the charge-containing device, hole sealing method and

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restriction of the charge or charge-containing device within the hole by heavy steel bar or structure, a controlled fracturing of the material may be realized.

One preferred fracturing involves the initiation and propagation of a fracture from the hole bottom such that the fracture propagates roughly parallel to the surface in which the hole was drilled.

This fracture will propagate with a lower expenditure of energy due to its relation to the free surface, and will thus remove and excavate the material more efficiently than will conventional drilling and blasting or boring. Due to the lower energies required for effective breakage of the material, the velocity imparted to the broken material is lower than for convention blasting, and thus machines and/or personnel may remain close to the face being drilled and excavated, allowing for the continuous operation of the process.

These and further and other objects and features of the invention are apparent in the disclosure, which includes the above and ongoing written specification, with the claims and the drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a schematic view of prior art penetrating cone fracture development from a rapidly pressurized borehole. The figure illustrates a general cone fracture trajectory.

Figure 2 provides details of cored, rounded, notched and percussively drilled hole bottoms evaluated in laboratory tests. Good cone fracture initiation was obtained in all of the percussively drilled holes.

Figures 3A, B and C are details of a mine gun having a tapered nozzle section and a helical shim for simple and effective sealing of the mine gun barrel in PCF holes.

Figure 4 further details the taper on the PCF gun barrel for improved borehole sealing, and also illustrates a double



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stepped borehole design.

Figure 5 illustrates a possible machine configuration using a drilling machine equipped with a boom that carries the PCF drill and PCF gun.

Figure 6 shows another possible configuration of the machine in which a mining machine chassis is modified with a boom for the PCF drill and PCF gun. A mucking apron and conveyor system is also illustrated.

Figures 7A, B and C show three possible toe mucking systems that are available for the modified miner chassis shown in Figure 6.

Figure 8 provides a more detailed illustration of the PCF boom extension with drilling, charge handling and firing capabilities.

Figures 9A and B illustrate a multiple stepped drill bit providing the small diameter change for borehole sealing, and the larger borehole change for gun clearance. The deepest, narrowest portion of the borehole is where rapid pressurization occurs and PCF breakage is initiated.

Figures 10A, B, C and D give details of a standard 50 caliber cartridge with a hollow shell to carry additional propellant.

Figures 11A and B are a schematic of the charge and blast apparatus showing the breech mechanism of the PCF gun. Modified 50 caliber cartridges are used.

DETAILED DESCRIPTION OF THE DRAWINGS

Figure 1 illustrates the prior art penetrating cone fracture (PCF) development which occurs when a substantially cylindrical borehole 1 is sealed and a propellant or explosive charge 3 is ignited within the hole. During combustion, the borehole is rapidly pressurized, and rock fracture is initiated along the perimeter of the hole bottom 5. The initial fracture typically propagates down into the rock and then turns towards the free surface as the surface effects become a factor. In contrast with earlier work done

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in this area, the penetrating cone fractures 7 in this disclosure are created using shallow boreholes with small propellant charges.

Figure 2 illustrates various hole types that can be used to facilitate PCF breakage. A hole 9 may be drilled having a hole bottom 11 with a sharp 90° corner. A rounded or worn carbide tip bit provides a hole bottom 13 with a rounded radius. Such a rounded hole bottom is detrimental. Another bit could be used which creates a cylindrical hole 15 that is notched 16 at the bottom of the hole, perpendicular to the sidewall of the hole. Extremely sharp, if not notched, borehole bottoms are conducive to successful cone fracture initiation. Preferred holes 17 and bottoms 18 are generated by a percussive drill bit. Although less sharp than the diamond core drilled hole bottoms, the percussively drilled holes 18 and bottoms 19 produce very good cone fracture initiation. The additional microflaw damage 19 induced in the rock by percussive drilling, particularly at the hole bottom radius, is more than adequate for consistent fracture initiation. Thus, the preferred percussive drilling of the borehole eliminates the necessity for construction of a specific hole bottom geometry.

Figure 3 illustrates a borehole sealing method using a brass shim strip 21 helically wrapped about the tapered section 23 of a mine gun barrel 25. While a simple cylindrical barrel mine gun may be used to seal the borehole, using the helical shim seal allows for better containment of gas pressure and higher peak pressure. The helical shim effectively cuts down on the escape of propellant gases during pressurization and fracture propagation, and also reduces erosion about the exterior of the mine gun barrel.

Figures 3B and 3C show a mine gun 27 with a propellant charge breech 29 and a threaded breach 31 which receives a plug closure 31. A ball and socket joint 33 has a stub 35 with a bore 37 which receives an end 39 of stemming bar 41.

Figure 4 shows another sealing means using a mine gun

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barrel particularly designed to seal a borehole 43 with double steps 45 and 47. The borehole is drilled so that a very small diameter change occurs at the sealing shoulder 45. Having a too-large diameter at the shoulder would allow significant chipping or fracturing to occur at the shoulder during pressurization, thus permitting gas pressure loss and hindering PCF breakage. The preferred small diameter change reduces such chipping or fracturing at the shoulder. The gun barrel 51 is tapered 53 to partially fit within the PCF hole 43 and form a seal 55 at the sealing shoulder 49.

Figures 5 and 6 illustrate embodiments of the mining apparatus. Commercially available crawler-type mining machines 57 are used in conjunction with one or more booms 59. The booms have rotational capabilities about their long axis. An extension 61 is mounted on the boom, containing hydraulic cylinders and having forward movement capabilities along the long axis of the boom. A pivot cone 63 is mounted on the extension and determines the axis of rotation for drill and blast sequences. The PCF gun 65 and the excavation drill 67 are mounted on opposing sides of the extension 61. A mucking apron 68 and conveyor system 69 are be attached to the mining carriage.

Figures 7A, B and C show three possible prior art mucking systems for use with the mining apparatus of the present invention. The standard mucking options use gathering arms 71, collection disks 73, or loading chains 75. Toe plates 77 and conveyors 79 are included. Machines equipped with pineapple or drum pick cutters are standard. Rock fragments generated in many mining operations consistently are fine and are readily handled by either the gathering disk or loading chain option. For machines modified with two booms and PCF drilling and charge handling equipment, the rock fragment size distribution generated includes more large fragments and fewer smaller fragments, and the gathering arm option would generally be preferable. Mucking is continuous while holes are drilled and blasted.



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Figure 8 illustrates the boom extension 61 having internal hydraulic cylinders 81, drilling 67, charge handling 83, and firing 65 capabilities. The hydraulic cylinders are contained within a sealed tube chassis 85. The extension is attached to the boom by a mounting plate. The drill 67 and gun 65 of both are mounted on the extension 61 with slide plates 81 and 89, and are further supported by cradles 91 and 93. The index pivot point 63 is centered on the end 64 of the extension 61 that is roughly parallel to the excavation face 66.

Figures 9A and B give details of the special carbide steel drill bit 95 used to create the small diameter change borehole for one of the sealing options. The three component combination bit includes steel carbide inserts 97, 98 for the stepped portions of the bit. The small diameter lead bit 99 for drilling the cone fracturing portion of the hole should experience the greatest amount of wear, and is separately replaceable.

Figures 10A, B C and D illustrate a 50 caliber cartridge 101 with a hollow shell 103 to carry additional propellant 104. The hollow shell or boot may be manufactured of plastic or aluminum. The aluminum shells or boots react somewhat with the burning propellant, providing for additional propellant energy, and the melted aluminum serves to further improve borehole sealing at the slightly stepped radius shoulder. For a slightly larger scale of PCF breakage or for an operation requiring considerably more propellant charge, standard 20 millimeter military cartridges may be used. Shell 101 has a primer cup 105, a primary charge 107 and an optional wadding 109.

Figures 11A and B show a breech mechanism for the PCF gun 111 utilizing modified 50 caliber cartridges 101. The gun has a simple, double acting hydraulic cylinder 113 to activate the breech block or bolt 115 shown in the figure. A swinging feed gate 117 is used to position the cartridges in alignment with the breech 119 as they are received from the

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cartridge feed tube 121. Swinging gate 117 is activated by an air or hydraulic cylinder. Cartridge removal is effected by a simple mechanical spring clip 123. A small air jet manifold 125 placed beneath the breech portion 125 of the gun is used for cartridge ejection.

Liquid propellants are particularly suited for use in the invention. The gun barrel is inserted, stemmed and sealed in a percussively drilled shouldered hole. Liquid is supplied to the chamber through an opening, the opening is closed, and the liquid propellant is ignited. Fractures promulgate from sites at the hole bottom, and a large, generally flat excavated portion is broken up and falls from the face for mucking and conveying out of the mine.

While the invention has been described with reference to specific embodiments, modifications and variations of the invention may be constructed without departing from the scope of the invention, which is described in the following claims.

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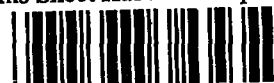
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1. An apparatus for breaking materials comprising:
 - (a) means for generating a gas;
 - (b) means for injecting generated gas into a hole in said material, wherein said means for generating is in communication with said means for injecting; and
 - (c) means for sealing said means for injecting in said hole to achieve increased pressure in said hole upon injection of gas into said hole.
2. The apparatus as claimed in Claim 1, wherein said means for injecting injects generated gas in the direction of the bottom of said hole to cause the formation and propagation of a fracture from a bottom corner of said hole.
3. The apparatus as claimed in Claim 2, wherein the bottom corner of said hole is notched to facilitate the formation and propagation of said fracture.
4. The apparatus as claimed in Claim 1, wherein said means for sealing comprises a shim operatively connected to said means for injecting.
5. The apparatus as claimed in Claim 1, wherein said hole is formed by drilling with a percussive drill to form fracture initiation sites in said hole.
6. The apparatus as claimed in Claim 1, wherein said means for injecting and said means for sealing comprise a tapered barrel.
7. The apparatus as claimed in Claim 1, wherein said means for injecting comprises:
 - (a) a substantially cylindrical barrel with a portion of said barrel having a smaller diameter than said hole;
 - (b) a bore in said barrel having an outlet to inject gas into said hole; and
 - (c) a chamber for containing said means for generating in communication with said bore.



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8. The apparatus as claimed in Claim 1, wherein said means for generating comprises a propellant charge and an ignition system for igniting said charge.

9. The apparatus as claimed in Claim 1, wherein said means for sealing comprises means for exerting a force on said means for injecting to substantially resist force exerted on said means for injecting by said increased gas pressure.

10. The apparatus as claimed in Claim 1, wherein said increased gas pressure is sufficient to initiate a fracture from a bottom corner of said hole.

11. The apparatus as claimed in Claim 1, wherein said means for sealing can maintain sufficient increased gas pressure in said hole to propagate a fracture from a bottom corner of said hole.

12. A method for breaking material comprising injecting gas into a hole in the material with a gas injection means wherein said gas injection means is sealed in said hole to form and propagate a fracture from said hole to break a volume of said material.

13. The method as claimed in Claim 12, wherein said hole has a depth to diameter ratio of about 2.5:1 to about 10:1.

14. The method as claimed in Claim 12, wherein said fracture is propagated from a bottom corner of said hole.

15. The method as claimed in Claim 12, wherein said gas injection means is sealed in said hole by engagement of a tapered portion of said gas injection means with said hole.

16. An apparatus for breaking material comprising:

(a) means for forming a hole in a surface of said material to be broken;

(b) means for injecting gas into said hole towards the hole bottom under pressure to cause the formation and propagation of a fracture from a bottom corner of said hole;

(c) means for generating said gas in communication with said means for injecting to supply gas to said means for injecting; and

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(d) means for aligning operatively connected to said means for forming and said means for injecting to consecutively align said means for forming and said means for injecting with said hole.

17. The apparatus as claimed in Claim 16, wherein said means for aligning rotates about an axis to consecutively align said means for forming and said means for injecting with said hole.



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