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[54] **DRILL-AND-BLAST EXCAVATING APPARATUS AND METHOD**
20 Claims, 8 Drawing Figs.

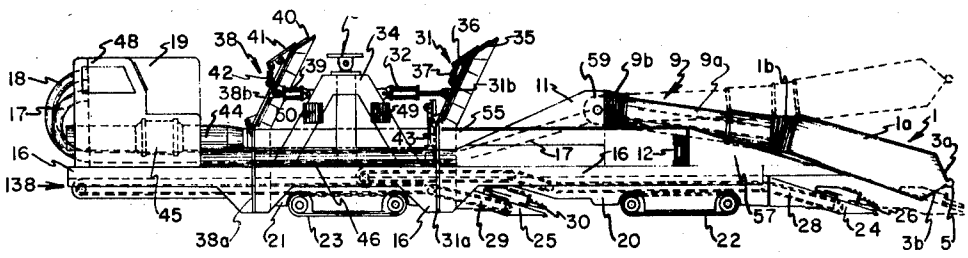
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[51] **Int. Cl.** **E01g 3/02,** E21c 37/00
[50] **Field of Search** 299/12, 13; 102/22, 23

[56] **References Cited**
UNITED STATES PATENTS

3,266,845	8/1966	Williamson et al.	299/13 X
3,511,538	5/1970	Guenter	299/13

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ABSTRACT: Drill-and-blast excavating apparatus has a powered carriage having a forward end which confronts a face in a geological formation; supporting arm members pivotally mounted on the carriage; drill-and-blast modules pivotally and rotatably mounted on the supporting arm members, the modules being adapted to drill holes in the face, load the holes with charges of condensed secondary explosive, and thereafter deliver energy to the charges in the holes to initiate the charges; explosives supply and feeding means communicating with the modules; a ventilating unit; at least one pair of gathering arms and a conveyor associated therewith mounted on the lower, chassis portion of the carriage; and protective shielding means including one or more transverse barriers mounted on the carriage behind the supporting arm members and drill-and-blast modules and forward of the explosives supply means, and adapted intermittently to engage the surrounding surfaces of an underground opening as a seal to effect pressure and noise attenuation. A process comprising performing substantially concurrent groups of drill-load-blast sequences in substantially continuous succession while removing muck and airborne fumes, and attenuating blast pressure and noise in an environmental transition region behind the face to the extent that blast pressure and noise levels in a zone behind the transition region, e.g., a zone up to about 50–100 feet from the face, are within prescribed safe limits of human tolerance.



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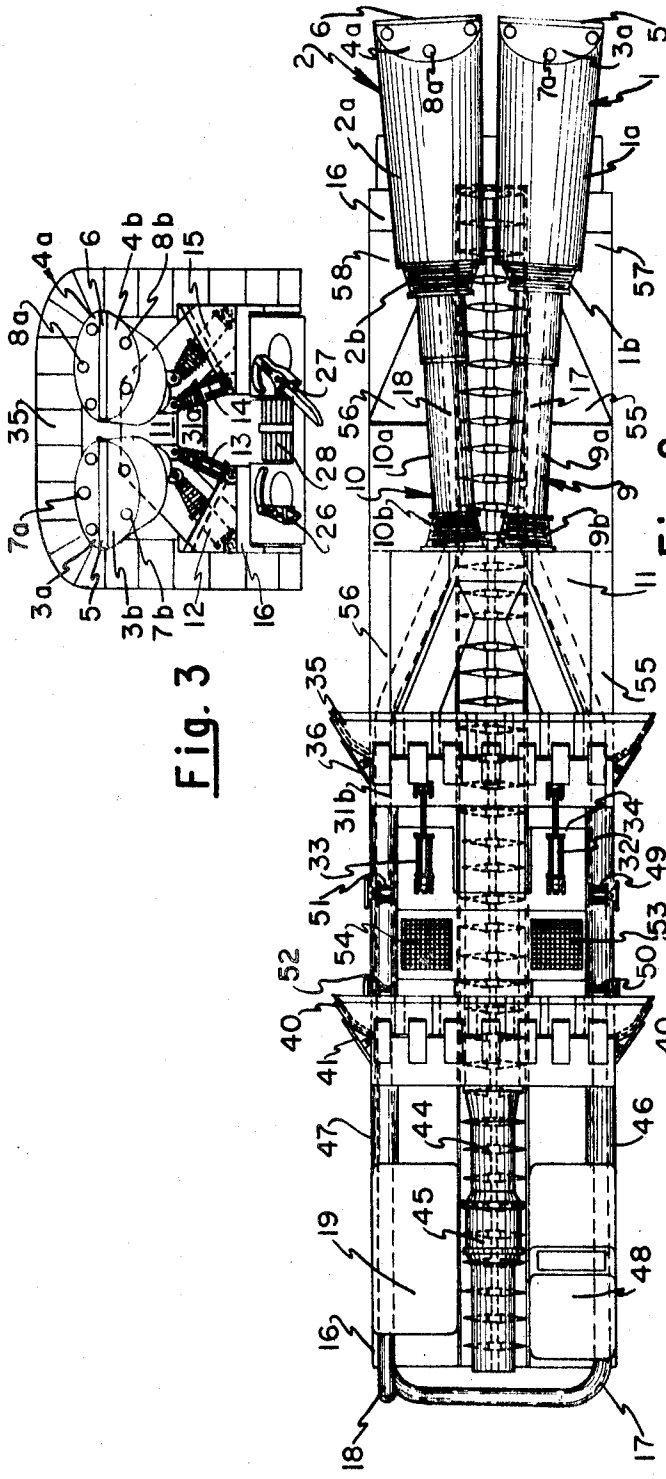


Fig. 3

Fig. 2

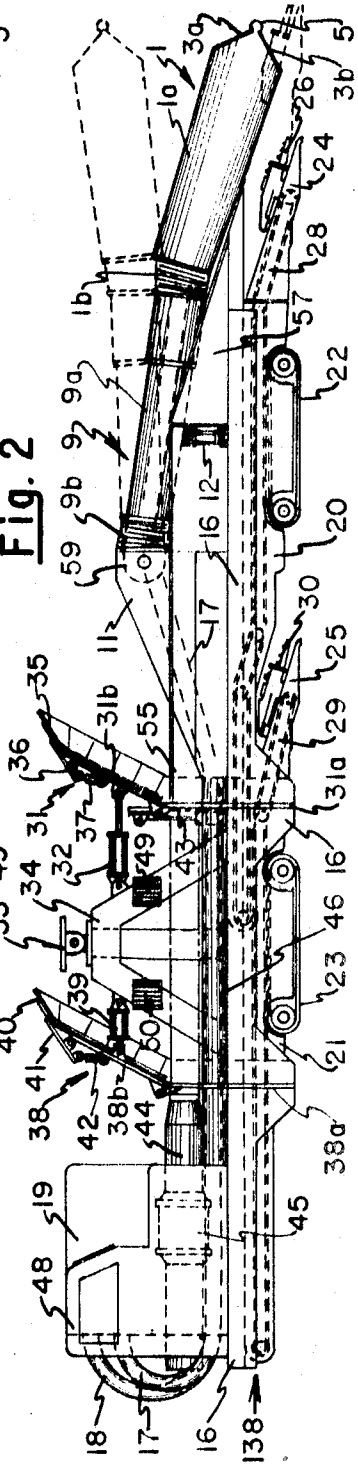


Fig. 1

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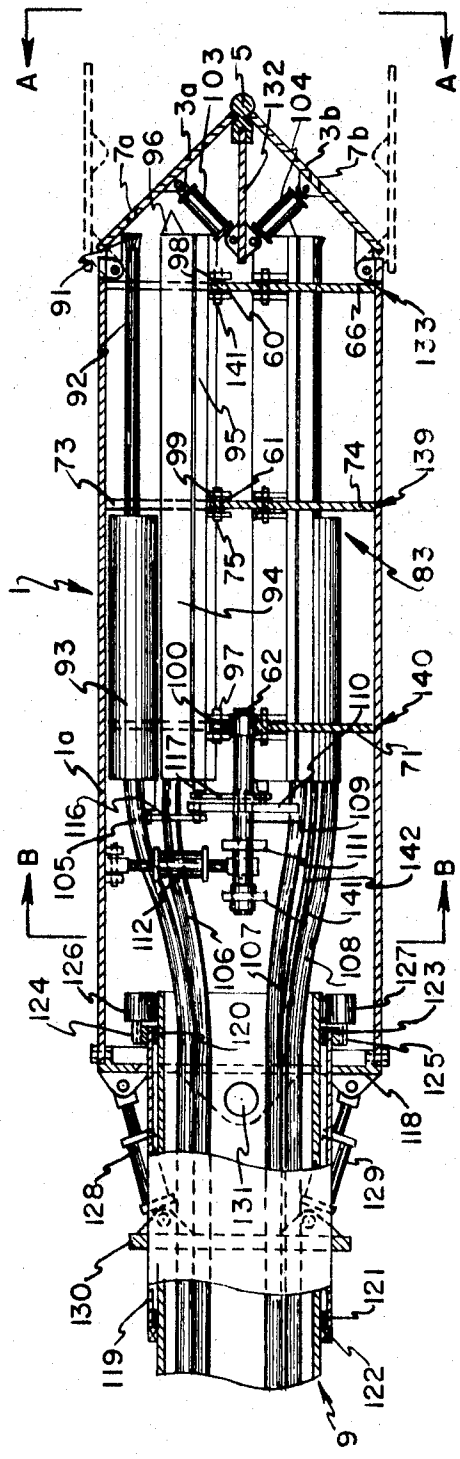


Fig. 4A

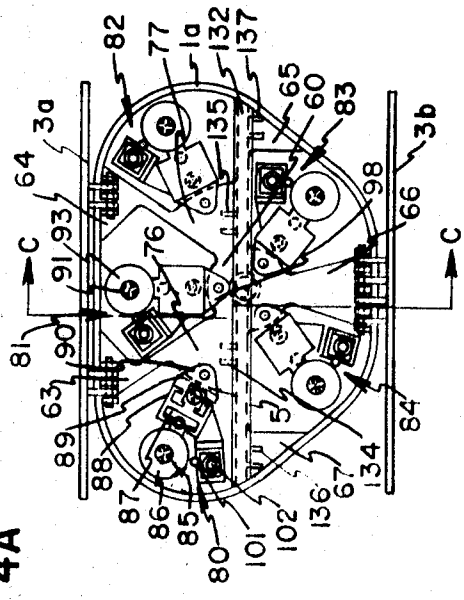


Fig. 4

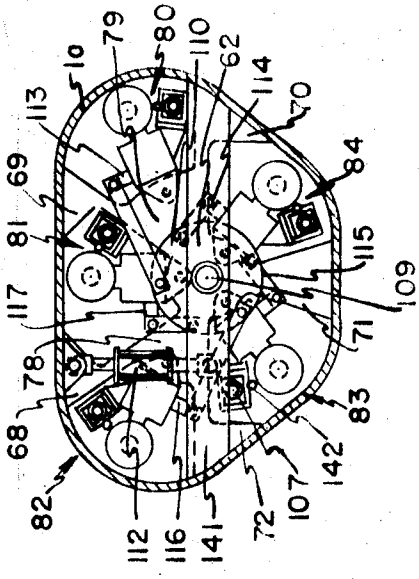


Fig. 4B

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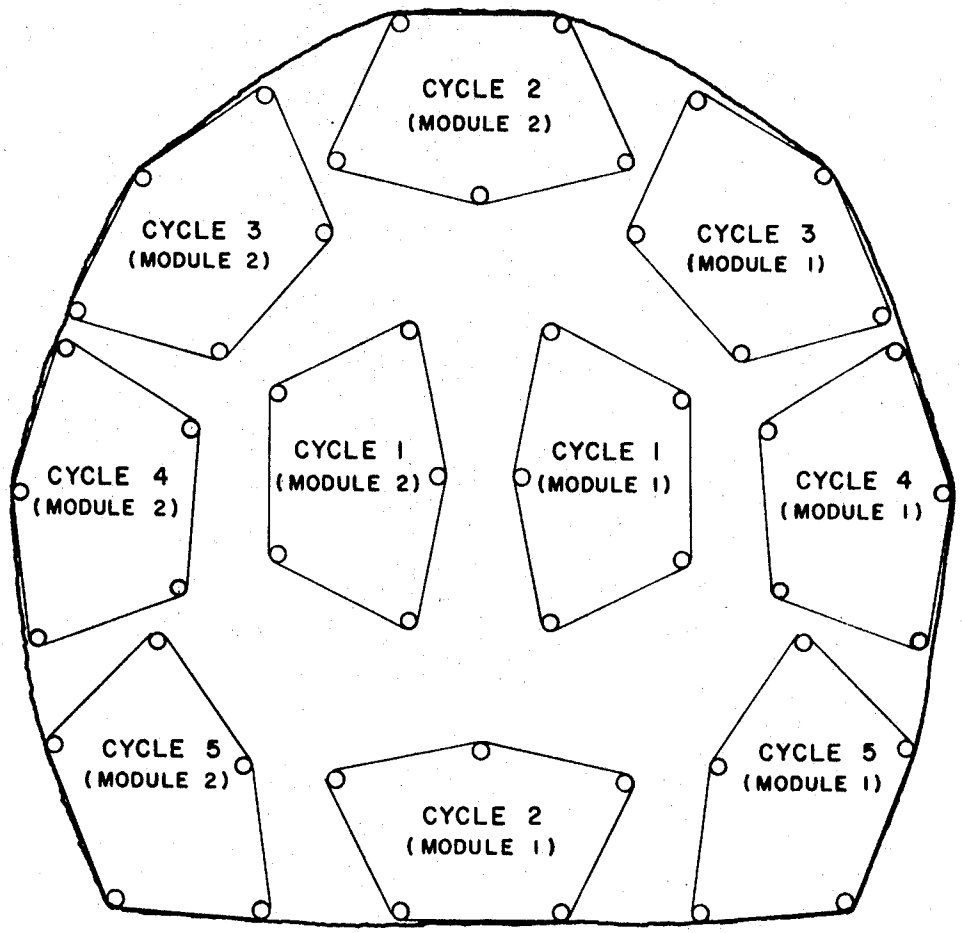
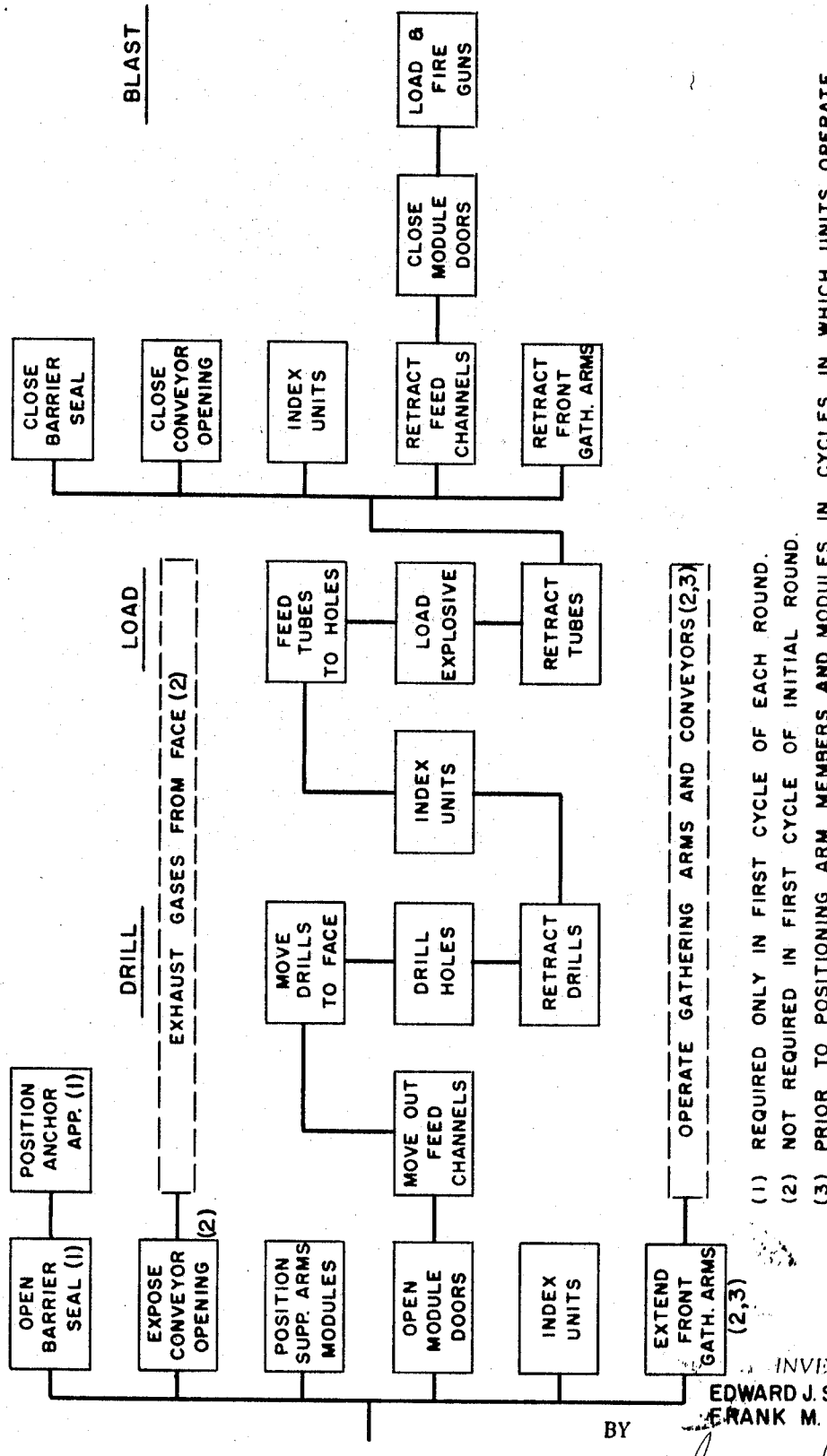


Fig. 5

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(1) REQUIRED ONLY IN FIRST CYCLE OF EACH ROUND.
(2) NOT REQUIRED IN FIRST CYCLE OF INITIAL ROUND.
(3) PRIOR TO POSITIONING ARM MEMBERS AND MODULES IN CYCLES IN WHICH UNITS OPERATE AT BOTTOM OF FACE.

Fig. 6

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DRILL-AND-BLAST EXCAVATING APPARATUS AND METHOD

BACKGROUND OF THE INVENTION

This invention relates to a mobile drill-and-blast excavation apparatus, and to a method of quasi-continuous excavation employing the apparatus.

Excavation is the process of digging out and removing material at or below the earth's surface either to form a useful cavity, e.g., in tunneling, or to derive profit from the removed material, e.g., in mining. Although at the present time there is an ever-increasing need for underground excavation, e.g., for constructing water and vehicle tunnels, parking spaces, and military defense sites, and for exploiting very large mineral deposits under conservation constraints, significant reductions in cost and increases in the sustained rate of heading advance are needed if underground construction and mining are to be utilized effectively to meet the challenges of urbanization and natural resource conservation.

In the conventional drill-and-blast method of underground excavation in a geological formation such as rock, holes are drilled in a predetermined pattern in the rock; after all of the holes have been drilled, a secondary explosive charge is loaded therein, usually by hand; an initiating device, i.e., a blasting cap or primer, in contact with the charge in each hole, or with detonating cord leading to the charge, is connected to a remotely located common actuating device such as a blasting machine; and the charges thereafter are initiated by energizing of the actuating device. After a ventilation period or "smoke time," which is necessary to clear the airborne fumes and dust produced as a result of such a blast, the round is concluded with the mucking operation, i.e., the loading and transporting of the disintegrated material (muck) from the excavation to a disposal area. This cycle of operations is then repeated.

In recent years, mechanical excavators, or "moles," have been developed which are capable of boring a tunnel or shaft, or mining out ore, by means of a rotating cutterhead driven by electric or hydraulic motors, the muck being picked up by scoops, mounted on the periphery of the cutterhead, which discharge the muck onto a belt conveyor that carries it back behind the machine. At their present respective levels of technological development, mechanical excavators have a greater driving capability per day in weak and medium-strength rock than the drill-and-blast method. This is due chiefly to the fact that the mechanical method involves a near-continuous operation, although delays are encountered because of changes in geological conditions, mechanical and electrical failures, the need for frequent cutter changes, etc.

There are serious limitations to the use of mechanical excavators, however. One of these is that mechanical excavators cannot be used economically in hard and/or abrasive rock, e.g., rock having a compressive strength of more than about 15,000–20,000 p.s.i. or a Moh's Scale hardness greater than about 5. Rock of this nature is presently encountered in about one-third of the excavation projects, and it is expected that this percentage will increase as future public construction demands force excavations to be made at greater depths and in areas of known hard-rock conditions. Also, the use of mechanical excavators in many short tunnels is limited either because of lack of economic justification in view of the high initial investment required, or because of the long waiting periods required for the construction or modification of the machines. Furthermore, investment in a new excavator usually is necessary in each mechanical tunnel-driving project because the different diameter requirements and geological conditions encountered from project to project necessitate the designing of a machine for each individual tunnel, even though machines which have been used in completed projects may still have some useful life. With respect to mining operations, continuous mining machines sometimes are too large and inflexible to permit the efficient mining of narrow ore seams. For reasons such as these, the drill-and-blast method of excavation is the method of choice in many operations at the present time.

As now practiced, however, the drill-and-blast method has inherent delays in each cycle which cause the rate of heading advance, or driving capability per day, to be low. The low rate of advance and requirement of large labor crews make the total excavation costs high. Cycle delays and high manpower requirements are inherent in the procedures presently employed to prepare the formation for the disintegration step, i.e., the blast, and by the condition of the environment in the work area during and after blast. The preparative operations include moving the drilling equipment up to the face, drilling the holes, moving back the drilling equipment, charging the holes with secondary explosive, tamping the explosive when required, and connecting the blasting leads (cap leg wires, or lengths of detonating fuse or safety fuse) to form a blasting circuit to a remote actuating device, e.g., a blasting machine or power line.

Because of the time required to drill, load, and otherwise prepare the holes for blasting, it has been necessary, in the interest of efficiency, to design the rounds (the drill hole arrangement at the face) to pull large cross-sectional areas of the face in one blast, e.g., the full cross-sectional area (full-face method), or a large part of it (top heading and bench method). Rounds of this size require a large number of drill holes and consequently the detonation of a large number of explosive charges. For example, for a full-face round in a typical railroad tunnel 28 feet high and 21 feet wide, about 900 pounds of explosive may be detonated per round. Because of the pressure and rock-throw effects resulting from blasts of this magnitude, the immediate blast area must be cleared of personnel and equipment. This is the reason why remote actuation of the initiating devices, and therefore connection of all of the charges into an energy-transmitting circuit, have been necessary.

Large single blasts such as have been employed heretofore can produce strong ground vibrations which may be detrimental to surrounding structures. In addition, such blasts produce large quantities of airborne fumes and dust which must be exhausted before personnel can move in with mucking equipment. Usually fans must be operated for a period of at least about 20 minutes to clear the area so that work can be resumed. After the "smoke time," the mucking machine is moved in, the round is mucked out, and the mucker is moved out.

Drilling procedures have been made more efficient in recent years with the introduction of modern drilling machines, such as pneumatic percussive drills mounted on a drill jumbo (a mobile work platform), and drill hole loading time can be reduced considerably by the use of such devices as a pneumatic cartridge loader having a semiautomatic breechpiece for feeding cartridges into a loading tube continuously, and a robot loader for displacing the tube axially so as to feed it into, and withdraw it from, the drill hole and tamp the explosive in the drill hole (both devices developed in Sweden). However, the efficient use of equipment and manpower still has necessitated large-round blasts, and delays therefore have remained considerable owing to the time required for moving the drilling equipment up to the face to be blasted; moving it back before the blast; moving the loading personnel and equipment in and out; performing the manual operations of connecting the blasting leads; and "smoke time." It can readily be seen that a considerable percentage of the time consumed in drill-and-blast operations as now practiced is time when neither disintegration nor mucking is taking place, and that disintegration and mucking cannot be performed in uninterrupted succession.

Obviously, the rate of advance could be increased, and costs reduced, in the drill-and-blast method of excavation if a means were to be provided which would eliminate the need for manual operations at the face, including the connection of the charges into a blasting circuit, and would mechanically perform all of the operations required to advance a face by drill-

and-blast while all of the necessary equipment remained stationed at the face. In other words, a drill-and-blast excavation apparatus is needed which is capable of performing the preparative and disintegration steps of the excavation process in rapid, uninterrupted, continuous, repetitive sequence, and mucking and ventilating operations simultaneously with the preparative steps, i.e., excavating on a quasi-continuous basis.

In considering a drill-and-blast excavating apparatus or machine, it is immediately clear that such a machine not only has to perform efficiently in terms of fragmentation and fragment removal, but also safely, a most important consideration since the machine is required to position detonable materials in drill holes and initiate the detonation of such materials at specified times. In order to protect the machine itself and, more importantly, personnel who may be stationed on or near the machine so as to be in close control of its operation, it is essential that the nature of the materials handled by the machine be such that there is no risk of accidental explosions of materials in or near the machine. Also, since the machine is required to confront a face while explosive charges are detonating in holes in the face, the environment at the face, i.e., fly rock, airborne fumes, blast pressures, and noise levels, needs to be isolable from the area where personnel are stationed. Not only must fly rock and fumes be prevented from arriving at the personnel area, but blast pressure and noise levels at the latter area must be reduced to within acceptable toleration limits.

U.S. Pat. No. 3,511,538 describes an excavation apparatus having a rotary cutter, for cutting a core in a rock face, and a shield provided with holes through which drills are operated to drill holes in the core, and through which special explosive cartridges having a delay charge therein, after having been ignited, are moved into the drilled holes and stemmed. Each cartridge is introduced into a drill hole individually, and detonates separately from other cartridges. The time at which the cartridges detonate depends on the time of ignition and on the amount and burning characteristics of the delay charges therein. There are several disadvantages to the use of such an apparatus, some of them of considerable significance with regard to safety considerations. In each cartridge, a percussion-actuated primer device is embedded in the base charge of blasting secondary explosive, e.g., about a half-pound charge. Thus, within each cartridge there is a completed connection between the relatively insensitive blasting explosive charge and the highly sensitive primary explosive charges (i.e., in a continuous reaction train in the cartridge: impact-sensitive ignition charge, flame-sensitive delay charge, flame-sensitive burning charge, heat-sensitive detonating charge, high-explosive primer charge, blasting charge), requiring only impact of the ignition charge to cause detonation. The storage of such cartridges and their passage through feed tubes in the apparatus are not without risk since unintentional impact of one or more of the primer cases in the storage area or in transit through the apparatus can result in accidental detonation of the cartridges, endangering personnel as well as disabling the apparatus. Of even greater concern, however, is the fact that the apparatus described in U.S. Pat. No. 3,511,538 manipulates "live," i.e., already ignited, cartridges. The cartridges are ignited before they leave the apparatus, and since their detonation is entirely out of the apparatus' control after ignition, no steps whatsoever can be taken to avoid detonations at unintended locations should any one of a number of possible mechanical failures occur after ignition, e.g., failure of the fluid pressure to advance and discharge the ignited cartridge from the conduit, failure of the cartridge feed mechanism to retract so as to withdraw the conduit from the blast hole before detonation, failure of the shield to index angularly to move the hole in the shield out of registry with the blast hole before detonation, etc. Thus, it can be seen that the sequence of steps performed by the described apparatus, i.e., drilling a hole, igniting an explosive charge, and thereafter loading the hole with the ignited charge is an extremely dangerous one.

In the apparatus described in the aforementioned patent, the drills and cartridge feed mechanisms are mounted on a plate behind a shield, and operate through holes in the plate and shield. This arrangement is disadvantageous for three reasons. First of all, the location and attitude of the holes drilled by the apparatus are fixed by the mounting location and attitude of the drills on the plate, and thus with a given drill mounting arrangement it is not possible to change the spacing between holes or groups of holes, the geometry of the overall hole pattern for a round, or the angle of the holes, or to add holes. Such changes may become necessary during the excavation process due to changing geological conditions or face profile. Secondly, due to practical limitations on the length of drills, a shield between the drills and the face has to be placed relatively close to the face, e.g., within 5–10 feet or less, a condition which requires the shield to be able to withstand maximum pressures due to the small volume between shield and face. Furthermore, a shield of the design shown in the patent in question does not provide attenuation of the blast pressure and noise attained with blasts of an economically acceptable size sufficient to permit men to be located behind the shield.

Thus, it can be seen that a means is needed whereby all of the operations required to advance a face by drill-and-blast are performed mechanically with the necessary equipment remaining stationed at the face, under conditions which assure (1) maximum safety against accidental detonation, (2) humanly tolerable blast pressure and noise levels at a selected location on or near the equipment, and (3) the capability of adapting blast patterns and sizes as required by changing geological circumstances.

SUMMARY OF THE INVENTION

This invention provides a mobile drill-and-blast apparatus for advancing a subsurface face in a geological formation, and a method of quasi-continuous excavation employing the apparatus.

The mobile excavation apparatus of the invention comprises

a. a powered carriage having a forward end which confronts a face to be advanced;

b. at least one supporting arm member, e.g., a boom, pivotally mounted at its back end on the carriage;

c. a plurality of drill-and-blast units positioned in at least one drill-and-blast module, the module being pivotally and rotatably mounted on the front end of a supporting arm member, the drill-and-blast units comprising (1) drilling means, (2) means for delivering a condensed secondary explosive charge into a hole made by the drilling means, and (3) means for delivering energy to the secondary explosive charge in the hole to initiate the charge, e.g., a gun which propels a high-velocity projectile into the explosive, the location, attitude, and mobility of each supporting arm member with respect to the carriage and other elements of the apparatus, and of each module with respect to its supporting arm member and other elements of the apparatus, being such that (A) the module can adopt a position wherein the operating end of each drill-and-blast unit therein is its leading end with respect to an intended direction of drilling and (B) with the apparatus in a position such that it confronts, and is separated from, the face, the drill-and-blast units' functional components have an unobstructed axial path in said direction;

d. explosives feeding means including explosives delivery hoses each of which has a forward end portion terminating in a drill-and-blast unit, the explosives feeding means being in communication with explosives supply means and adapted to deliver explosive material from the explosives supply means, through the explosives delivery hoses, and out of the free forward ends of the hoses when the latter are in communication with drill holes;

e. means mounted on the carriage for collecting and transporting solid fragments, the collecting means being adapted to move fragments to the transporting means from the path of the apparatus at the forward end of the carriage, and the transporting means being adapted to move fragments away from the apparatus;

f. ventilation means adapted to draw airborne fumes away from the face and cause fresh air to move up to the face; and

g. shielding means adapted to protect components of the apparatus from blast pressure and rock impact, the shielding means comprising (1) at least one transverse barrier mounted on the carriage behind the supporting arm member and drill-and-blast module and forward of the explosives supply means, and being adapted intermittently to engage the surrounding surfaces of an underground opening as a seal, and (2) armored housing on the supporting arm member and module, the transverse barrier having at least one opening therein through which (A) the fragment-transporting means extends so as to communicate with the fragment-collecting means at the forward end of the carriage, (B) the explosives delivery hoses extend so as to terminate in the drill-and-blast units, and (C) the ventilation means extends to the space between the ventilation means and the face, all openings in the transverse barrier which permit communication between the external environments ahead of and behind the barrier being adapted to be closed off intermittently.

When the energy-delivering means of the drill-and-blast units are guns, the apparatus also includes projectile supply means, also behind one or more transverse barriers, in communication with projectile feeding means including projectile delivery hoses, each of which passes through an opening in the transverse barrier and communicates with the chamber of a gun in each drill-and-blast unit, the projectile feeding means being adapted to deliver a projectile from the projectile supply means, through the delivery hoses, and into the gun chambers.

When the apparatus of this invention is stationed and operated at a location which confronts, and is separated from, a subsurface geological face to be advanced, e.g., a location where the operating ends of the drill-and-blast units are about 1 to 6 feet away from the face, excavation is performed by a quasi-continuous process also provided by this invention and which comprises (a) performing a substantially continuous succession of groups of substantially continuous drill-load-blast sequences, each sequence at a single location in the face different from the locations therein where other sequences are performed, the sequences in each group being carried out substantially concurrently, and each sequence comprising the steps of (1) drilling a hole in the face, (2) placing a charge of condensed secondary explosive in the hole, and (3) delivering energy to the secondary explosive charge in the hole, e.g., by projecting propagative energy, such as kinetic energy of motion via a projectile, to the charge, in a manner such that energy is released into the charge at a rate sufficiently high to cause detonation thereof; (b) concurrently with steps (a) (1) and (a) (2), removing from the vicinity of the face dislodged fragments and airborne fumes produced during step (a) (3) of the previous group of sequences; and (c) attenuating blast pressure and noise in an environmental transition region behind the face, preferably at a location such that the volume between this region and the face is at least about 150 cubic feet per pound of explosive placed in holes in each concurrent group of sequences, to the extent that the blast pressure and noise levels in a zone behind the transition region, e.g., a zone up to about 50–100 feet from the face, are within prescribed safe limits of human tolerance.

The apparatus of the present invention is an excavating machine which makes use of the power of detonating explosives to cause fragmentation. As a machine which performs all of the operations required to advance a face by drill-and-blast while remaining stationed at the face, the apparatus can afford the high-advance-rate capability of totally mechanical excavators without their limitations, e.g., their inability to excavate hard rock and inadaptability for use under greatly changing geological conditions. In addition, whereas totally mechanical excavators are restricted to use with a given size and configuration of face, the present apparatus is easily adaptable to use with changing face sizes and configurations by modification of the number, size, and/or positioning of the drill-and-blast modules therein. The apparatus of the invention can advance a face in a succession of small blast cycles, a "blast cycle" referring to the multiple drill-load-blast sequences performed as a substantially concurrent group. In small-blast-cycle operation, of the total number of sequences performed (number of drill holes made, loaded, and blasted) to advance an entire face, only a portion, e.g., about 5–50 percent, and usually about 10–35 percent, of the total number of sequences, are performed per blast cycle. Since the apparatus has the capability, in rapid sequence, of drilling and loading holes with secondary explosive, and thereafter delivering energy to the explosive to initiate it, and also of removing muck and airborne fumes and dust from the face and attenuating blast pressure and noise during the drill-load-blast sequences, and since the apparatus remains stationed at the face throughout the process, use of the apparatus eliminates the delays heretofore required in the performance of the drill-blast technique, i.e., time needed to move equipment up to and back from the face, connect blasting leads, clear the area of equipment and personnel, "smoke time," and exclusive mucking time. Deleterious effects of large blasts, e.g., strong ground vibrations, also can be eliminated.

The apparatus and process of this invention overcome the limitations of totally mechanical excavators as well as the disadvantages of conventional large-blast-cycle drill-and-blast processes while at the same time affording maximum safety against accidental detonation, a safe environment for personnel during blast, and flexibility with respect to changing drill hole locations as may be required. With respect to safety against accidental detonation, in the present apparatus the relatively insensitive secondary explosive used for blasting is handled separately from the means used to initiate it. There is no primary explosive in a continuous reaction train with the blasting explosive in the present apparatus. More importantly, there is no preignition of explosive in the apparatus. After the secondary explosive charges have been placed in the drill holes, the detonation of the charges is under the control of the apparatus, which delivers initiating energy to the explosive in the holes only after the required mechanical operations have been performed, e.g., retraction of the explosives delivery tubes from the drill holes, closing of doors and other sealing means in the shielding means, etc. A safe environment for personnel during blast is provided in the present apparatus by one or more transverse barriers adapted to engage the surrounding surfaces of an underground opening as a seal to effect pressure and noise attenuation. The transverse barrier(s) are located behind the supporting arm member(s) which bear the drill-and-blast modules. Such positioning of the barrier(s) is advantageous in that (1) the pressures to which the barrier(s) are exposed are minimized owing to the relatively large volume between the barrier(s) and the face, and (2) the positions of the drill-and-blast modules are not restricted to those corresponding to apertures in the barrier. In the apparatus of the invention, the modules are pivotally and rotatably mounted on pivotable supporting arms forward of the transverse barrier(s) and are free to move to new positions as may be required.

The "drill-and-blast module" which functions as the fragmenting device in the apparatus of this invention can be of the type described in detail in copending, coassigned U.S. Pat. application Ser. No. 878,005, filed Nov. 19, 1969, the disclosures of which are incorporated herein by reference. This drill-and-blast module is comprised of at least one unit in which three basic working components are grouped in a specific manner, i.e., drilling means, an explosives-delivery or drill-hole-loading tube or hose, and energy-projecting means,

preferably a gun, all mounted on support means in a manner such that the drill bit, discharge end of the delivery tube, and energy-exiting end of the energy-projecting means, e.g., gun muzzle, are located near a common, operating end, and the support means preferably being movable by an indexing means that is adapted to sequentially position the drilling means, explosives-delivery tube, and energy-projecting path of the energy-projecting means on substantially the same common axis. In addition, the drilling means and explosives-delivery tube are axially movable with respect to the support means to permit the drill bit and the discharge end of the explosives-delivery tube to extend sequentially beyond all other components of the module in an axial direction at the operating end. With these basic components and motions, each unit of the module can, in rapid succession, drill a hole in a geological mass, load secondary explosive into the drill hole, and project energy to the secondary explosive to initiate it, thereby causing fragmentation of the mass.

BRIEF DESCRIPTION OF THE DRAWINGS

In the accompanying drawings which illustrate specific embodiments of this invention:

FIG. **1** is a side elevational view of a drill-and-blast excavating apparatus of this invention;

FIG. **2** is a plan view of the apparatus illustrated in FIG. **1**;

FIG. **3** is a front view of the apparatus illustrated in FIG. **1**;

FIGS. **4** and **4A** are front and side elevational views, respectively, of the interior of the drill-and-blast module shown in FIGS. **1**, **2**, and **3**, the view in FIG. **4** being that along line A—A in FIG. **4A**, and the view in FIG. **4A** being that along line C—C in FIG. **4**;

FIG. **4B** is a back elevational view of the drill-and-blast module shown in FIGS. **4** and **4A** as viewed along line B—B in FIG. **4A**;

FIG. **5** is a typical blast cycle pattern for advancing a tunnel face with the apparatus illustrated in FIGS. **1** through **4B**; and

FIG. **6** is a block diagram of a typical order of operations performed in the present process by the apparatus illustrated in FIGS. **1** through **4B** to advance a tunnel face.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The excavating apparatus illustrated in FIGS. **1**, **2**, and **3** has at its forward end two composite drill-and-blast modules **1** and **2**, each comprising five drill-and-blast units supported and clustered within a common enclosure or housing. Each module has a front end closure comprised of two doors, *3a* and *3b* in module **1**, and *4a* and *4b* in module **2**, which slope forward toward one another and fit against the surfaces of a linear bumper member, i.e., **5** in module **1**, and **6** in module **2**, along which they are adapted to open and close. This whalemouth closure gives the forward end of the modules a wedge-shaped design, resulting in a greater degree of glancing, rather than head-on, impact of fly-rock. Doors *3a* and *4a* each have three apertures therein, *7a* and *8a*, respectively; and doors *3b* and *4b* each have two apertures therein, *7b* and *8b*, respectively. Apertures *7a* and *7b*, and apertures *8a* and *8b*, fall on axes along which energy is delivered from the five units of module **1** and of module **2**, respectively, to initiate condensed secondary explosive charges in drill holes, the pair of doors in each module being closed during energy delivery to the explosive.

Modules **1** and **2** are pivotally and rotatably secured to the front ends of tubular supporting arm members **9** and **10**, respectively, which in turn are pivotally secured at their back ends to arm-mounting member **11**, affixed to upper portion or frame **16** of powered carriage **138**. Arm members **9** and **10** are mounted side-by-side into mounting member **11**, through apertures in the latter's front vertical surface via a pivotal joint (**59** on arm-member **9**, shown in FIG. **1**) in a manner such that the arms are capable of being lifted and lowered (as indicated by dotted lines in FIG. **1**), and swung right and left. Motion of arm members **9** and **10** is achieved by operation of two arm-positioning cylinders, **12** and **13**, secured to supporting arm member **9**, and two arm-positioning cylinders, **14** and **15**, secured to supporting arm member **10**. The piston rod of each arm-positioning cylinder is pivotally attached to the under portion of a supporting arm member while the cylinder portion is pivotally attached to the upper portion or frame **16** of powered carriage **138**. Modules **1** and **2**, supporting arm members **9** and **10**, and arm-positioning cylinders **12**, **13**, **14**, and **15** are armored, i.e., they have an outer shell or housing capable of withstanding air blast and impact effects. Housing portions *1a*, *2a*, *9a*, and *10a* are rigid and metallic, e.g., made of steel; while housing portions *1b*, *2b*, *9b*, and *10b* are deformable, e.g., in the nature of a protective bellows. Supporting arm members **9** and **10**, and the mountings associated therewith, both have a passageway therethrough allowing for the passage of module feed lines, **17** and **18**, respectively, as well as hydraulic, pneumatic, and electrical lines to mechanisms in the modules. Module feed line **17** and module feed line **18** carry five explosives loading or delivery hoses, one to each drill-and-blast unit in module **1** and module **2**, respectively, the forward end of each hose there becoming the explosives delivery tube of a unit. In the present instance, module feed line **17** and module feed line **18** also carry five projectile delivery hoses, one to each drill-and-blast unit in module **1** and module **2**, respectively, each hose there passing into the chamber of a gun in a unit. The explosives delivery hoses and projectile delivery hoses in module feed lines **17** and **18** are a part of the explosives and projectile feeding means which communicate with explosives and projectile supply units located at the rear of the apparatus at supply unit **19**. For feeding projectiles and cartridged explosive, e.g., dynamite, a suitable feeding means is a pneumatic cartridge loader having a semiautomatic breechpiece for feeding cartridges into the delivery hoses. A pump is used to feed pumpable explosive, e.g., slurries.

The internal structure of the modules can be ascertained by referring to FIGS. **4**, **4A**, and **4B**. FIG. **4** is a front view of module **1** when doors *3a* and *3b* are open. The internal support structure for the five units consists of three like cutout support plates **133**, **139**, and **140**, each of which has a circular disclike central portion and three arm portions radiating laterally therefrom in the plane of the central portion in the positions shown in FIGS. **4** and **4B**. One arm portion of each support plate extends directly to the inside wall of the module housing, while two arm portions of each support plate are bifurcate, their branched arm portions extending to the housing wall. Thus, each support plate has a total of five arm portions. As seen in FIG. **4**, front support plate **133** has a central circular disclike portion **60** with five arm portions **63**, **64**, **65**, **66**, and **67**, arm portions **63** and **67** branching from bifurcate arm portion **76**, and arm portions **64** and **65** branching from bifurcate arm portion **77**. Five arm portions **68**, **69**, **70**, **71**, and **72** radiating from disclike portion **62** of back support plate **140** can be seen in FIGS. **4A** and **4B**, arm portions **68** and **72** branching from bifurcate arm portion **78**, and arm portions **69** and **70** branching from bifurcate arm portion **79**. Two arm portions, **73** and **74**, radiating from disclike portion **61** of middle support plate **139** are seen in FIG. **4A**. In each cutout support plate, the two arm portions which are bifurcate (e.g., **76** and **77** in the front plate) are symmetrical with respect to the distance between the location of branching and the center of the disclike portion. The three support plates **133**, **139**, and **140** are positioned concentrically and substantially normal to the longitudinal axis of the module, substantially parallel to each other, with substantially the same spacing between each pair of plates, and with all corresponding arm portions in substantial alignment along the module's longitudinal axis, i.e., with the bottom edge surfaces of arm portions **66**, **71**, and **74** bisected by substantially the same straight line. All 15 arm portions which extend to the inside wall of module housing portion *1a* are fixedly attached thereto.

Drill-and-blast units **80**, **81**, **82**, **83**, and **84** are pivotally mounted to cutout support plates **133**, **139**, and **140**, fitting in the spaces between the arm portions thereof. Each unit is

mounted at a corresponding pivot point, one on each of the three support plates, all three pivot points being substantially on the same line. Units **81**, **83**, and **84** are mounted on disclike portions (**60**, **61**, and **62**), and units **80** and **82** on the bifurcate arm portions (**76** and **79**, **77** and **78**, respectively). All five units have the same structure. Referring to unit **80** in FIG. **4**, in which the drill structure is shown in detail, **85** is a drill bit at the forward end of the drill steel (rod); **86** a motor, e.g., a pneumatically or hydraulically operated motor, which provides drill action (reciprocation and rotation); **87** a drill feed (motor-driven chain or screw feed); **88** a drill feed channel (the chain feed or screw feed moves the drill steel axially on the feed channel and applies feed pressure or thrust for drilling); **89** a fixed slide member having an axial groove through which feed channel **88** is moved back and forth in an axial direction by means of a cylinder; and **90** a clevis through which the unit is joined to arm portion **76**. Referring to unit **81** in FIGS. **4** and **4A**, **91**, **92**, **93**, **94**, and **95** are the drill bit, drill steel, drill motor, drill feed channel, and fixed slide member, respectively; **96** is a "stinger," and **141**, **75** and **97** are pins which pass through apertures in disclike portions **60**, **61**, and **62**, respectively, and through clevises **98**, **99**, and **100**, which are affixed to slide member **95** and fit over the apertures in disclike portions **60**, **61** and **62**, respectively.

A gun and an explosives delivery tube are mounted adjacent the drill on the axially movable drill feed channel in each unit (**101** and **102**, respectively, in unit **80**), the longitudinal axes of the drill, gun, and delivery tube of a given unit being substantially parallel to one another, and at substantially the same radial distance from the centers of disclike portions **60**, **61**, and **62**. In the positions of the units shown in FIGS. **4** and **4B**, the drill steels of units **80**, **81**, and **82** lie on axes which pass through apertures **7***a*, and the drill steels of units **83** and **84** on axes which pass through apertures **7***b*, in doors **3***a* and **3***b* when the latter are in a closed position, as they are shown in FIG. **4A**. Door **3***a* and door **3***b*, which are pivotally mounted to the front end of module housing portion **1***a* at the top and bottom thereof, respectively, are adapted to be opened and closed, each by means of two cylinders, one of the two cylinders for moving door **3***a*, i.e., **103**, and one for moving door **3***b*, i.e., **104**, being shown in FIG. **4A**. The door-moving cylinders have their piston rods pivotally mounted to the doors and their cylinder ends pivotally mounted to horizontal support plate **132**, which spans the width of the module extending back to a position ahead of front cutout support plate **133**. The side edges of plate **132** are affixed to the walls of module housing portion **1***a*. The front edge of plate **132** fits into a mating portion in bumper member **5**, e.g., a member made of tough elastomeric material. Doors **3***a* and **3***b* close against the surfaces of bumper member **5**. Clevises **134** and **135** at which the two door-moving cylinders for door **3***a* are mounted, and clevises **136** and **137** at which the two door-moving cylinders for door **3***b* are mounted, are shown in FIG. **4**, the cylinders being omitted to show the other components more clearly. In FIG. **4A**, hoses **105**, **106**, **107**, **108**, and **142** are some of the pneumatic and hydraulic lines leading to the guns, explosives delivery tubes, motors, and cylinders in the modules from supply unit **19** and control cab **48** at the back end of the apparatus, **107** being a delivery hose of the explosive feeding means of the apparatus, e.g., a pneumatic loader, the feeding means communicating with the explosives supply means, e.g., a magazine, at supply station **19**, and the forward end portion of hose **107** constituting the explosives delivery tube of unit **83** (FIG. **4B**). The delivery hose of the explosives feeding means (e.g., **107**) including the forward end portion thereof in the drill-and-blast unit can be a single hose or multiple hoses joined together. Hose **142** is the delivery hose of a pneumatic loader which comprises the projectile feeding means of the apparatus, the loader communicating with the projectile supply means, i.e., a magazine, at supply station **19**, and hose **142** communicating with the chamber of a gun in unit **83**. Hoses **105**, **106**, and **108**, and the portions of hoses **107** and **142** outside unit **83** are omitted in the view shown in FIG. **4B** in order that other module components may be seen more clearly.

Cylindrical shaft **109** passes through concentric bearing apertures in disclike portion **62** of cutout support plate **140** and in horizontal support bar **141**, and is adapted to be rotated therein. A circular indexing disc, **110**, and an indexing crank, **111**, are fixedly mounted on cylindrical shaft **109**, the shaft passing through concentric circular apertures in the disc and crank. The disc and crank are spaced from one another and are mounted in substantially parallel planes. A dual-piston, three-position cylinder, **112**, has one piston rod pivotally mounted on a pin in indexing crank **111** parallel to, and offset from, cylindrical shaft **109**; and a second piston rod pivotally mounted to the inner wall of module housing portion **1***a*. When the drill-and-blast units are in the positions shown in FIGS. **4** and **4B**, cylinder **112** is substantially normal to the line passing through points on crank **111** joining the pin and the shaft. Units **80**, **81**, **82**, **83**, and **84** are coupled to indexing disc **110** via fixed arm linkages between the fixed slide members of the units and appropriate surface portions of the indexing disc (arm linkages **113**, **114**, **115**, **116**, and **117** on units **80**, **84**, **83**, **82**, and **81**, respectively). Arm linkages **116** and **113** are affixed to the back surface, and arm linkages **114**, **115**, and **117** to the front surface, of the indexing disc.

The drill-and-blast units shown in FIGS. **4** and **4B** are in the drill position, i.e., the drill steels lie on axes which pass through the apertures in doors **3***a* and **3***b* and into the holes the units are intended to make and work on. The units are adapted to be indexed, i.e., to be moved so that the drills, explosives delivery tubes, and guns can be positioned on these axes in sequence as required. For example, to index the units from the drill position shown in FIGS. **4** and **4B** to the loader position (explosives delivery tubes to take the positions occupied by the drills), cylinder **112** is actuated (both pistons extended) so as to rotate indexing crank **111**, shaft **109**, and indexing disc **110** in a clockwise direction (as viewed from the front of the module). Rotation of disc **110** causes the units linked thereto to rotate in the same direction about the pivots by which they are attached to the fixed supporting plates. To index from the loader position to the gun position, cylinder **112** is again actuated (one piston retracted), this time to rotate the units in a counterclockwise direction.

Also shown in FIG. **4A** is the design of a joint between supporting arm member **9** and module **1**, which design provides the means of effecting the required pivoting and rotating of the module with respect to the supporting arm member (housing portion **1***b* not shown in order to show other elements more clearly). At its back end, module **1** has a closure plate **118** which is fastenable to housing portion **1***a* by means of bolts. The forward end of supporting arm member **9** is fitted with a surrounding concentric sleeve member **119**, which is supported by sleeve bearings **120** and **121** at both ends, and thrust bearing **122** at the back end. Sleeve member **119** fits through an opening in closure plate **118** so that the forward ends of arm member **9** and sleeve member **119** are inside module **1** when closure plate **118** is in place. Sleeve member **119** at its forward end, has affixed thereto surrounding ring gear **123**, which engages pinions **124** and **125**, the latter being driven by motors **126** and **127**, respectively. Cylinders **128** and **129** have their piston ends pivotally mounted to opposite sides (top and bottom) of closure plate **118** and their cylinder ends pivotally mounted to annular mounting member **130**, which surrounds sleeve member **119** in fixed position. Also mounted to opposite sides (horizontal direction) of closure plate **118** is a pair of clevises through which a pin **131** passes, this pin providing a pivot axis for module **1**.

Rotation and tilting of module **1** is accomplished by energizing motors **126** and **127**, thereby rotating pinions **124** and **125**, and thus also ring gear **123**. Rotation of ring gear **123** causes sleeve member **119** to rotate, and with it module **1**, pin **131**, mounting member **130**, and cylinders **128** and **129**. The module can be tilted in any desired direction by actuating cylinders **128** and **129** when pin **131** is in the desired attitude.

Referring again to FIG. **1**, upper portion or frame **16** of carriage **138** rests upon a two-part chassis having a front frame segment **20** and a rear frame segment **21**. Front chassis seg-

ment 20 is mounted on a pair of spaced crawlers 22, and rear chassis segment 21 on a pair of spaced crawlers 23, all driven by hydraulic, pneumatic, or electric motors (not shown). The front end of chassis segment 20, and that of chassis segment 21, are formed into loading aprons or decks, 24 and 25, respectively, which slope downwardly to the ground at their forward ends and are adapted to be raised and lowered with respect to the remainder of the carriage. Mounted on apron 24 are two gathering arms, 26 and 27, which reciprocate around vertical axes, sweeping material in their path onto the forward end of a front endless chain and flight conveyor 28 mounted on front chassis segment 20 on a longitudinal axis substantially midway between the reciprocating axes of arms 26 and 27. Toward its back end, front conveyor 28 extends over a pair of gathering arms mounted on deck 25 and over the forward end of a rear endless chain and flight conveyor 29 over which the arms (one of which, 30, is shown in FIG. 1) on deck 25 sweep, rear conveyor 29 being mounted on rear chassis segment 21 on a longitudinal axis which is in substantially the same vertical plane as the axis of conveyor 28, and extending from the gathering arms on deck 25 to the back end of the machine. Crawlers 22 can be driven independently of crawlers 23, and front chassis segment 20 is in slidable engagement with frame 16, thereby giving front chassis segment 20 the capability of independent forward (extension) and backward (retraction) motion with respect to the remainder of the carriage, the back end of front conveyor 28 remaining directly above rear conveyor 29 at all times regardless of whether conveyor 28 is extended or retracted.

Mounted on carriage frame 16 behind arm-mounting member 11 is a segmented transverse metal barrier 31 comprised of a lower segment 31*a*, which is fixedly mounted to frame 16 in a substantially vertical attitude, and an upper segment 31*b* which is pivotally secured to the upper edge of lower segment 31*a* thereby enabling the upper segment to pivot about a horizontal axis. Tilting and lifting of upper segment 31*b* is achieved by the action of cylinders 32 and 33, the piston rods of which are pivotally connected to the back surface of upper barrier segment 31*b* and the cylinder ends to a generally A-shaped stabilizing member 34, fixedly mounted on frame 16 behind barrier segment 31*a*. Mounted near the side and bottom edge surfaces of segment 31*a* and the side and top edge surfaces of segment 31*b* are a number of rectangular tabs or flaps 35 which overlap at their adjacent sides and are made of a tough but somewhat flexible material, such as fiber- or metal-reinforced rubber. A separate metal plate 36 is fastened, near one of its edges, to each flap 35, each plate 36 being pivotally connected near its opposite edge to the piston rod of a separate cylinder 37, the cylinder end of which is pivotally connected to the back surface of the barrier segment, 31*a* or 31*b*, concerned. Plates 36 are also pivotally connected to barrier segments 31*a* and 31*b* near the edge surfaces of the segments. Actuation of cylinders 37 thus permits independent forward and backward motion of flaps 35 fastened to plates 36, which act as hinges. The extension layer around the edges of segments 31*a* and 31*b* engages the walls, ceiling, and floor of a tunnel and acts to seal off the environment ahead of the transverse barrier so as to reduce pressure and noise levels at the back end of the apparatus. The independently movable hinged flap design of the layer permits it to form a seal with irregular and variable wall and ceiling configurations.

A second transverse metal barrier 38, substantially the same as the one just described, is fixedly mounted on carriage frame 16 behind stabilizing member 34. Members 38*a*, 38*b*, 39, 40, 41, and 42 on the second barrier are counterparts to members 31*a*, 31*b*, 32, 35, 36, and 37. The second barrier provides additional capability in pressure and noise level reduction.

Barrier segment 31*a* has an opening therein through which conveyors 28 and 29, and material carried thereon, pass. Similarly, barrier segment 38*a* has an opening therein to allow the passage of rear conveyor 29 and material carried thereon. A metal plate 43 is mounted on frame 16 directly behind barrier segment 31*a*, and substantially parallel thereto, by means of two lugs attached one to each side of the plate and extending laterally therefrom, each lug being pivotally connected to the piston rod of a cylinder pivotally mounted on frame 16. The sides of plate 43 fit in guiding channels through which the plate is moved up and down by actuation of the cylinders. When plate 43 is in its lowered position, it covers the conveyor opening in segment 31*a* as far down as front conveyor 28 and, together with material amassed before it on conveyor 28, effectively seals the opening. When plate 43 is in its raised position, material on conveyor 28 is allowed to move back freely. The conveyor openings in barrier segments 31*a* and 38*a* are joined together by a duct (not shown) which fits snugly in the opening in barrier segment 38*a* and extends up to plate 43. Thus, operation of plate 43 seals and opens the opening in barrier segment 38*a* as well. The conveyor openings in barrier segments 31*a* and 38*a* can serve also as manways to the forward end of the apparatus.

Ventilation duct 44 leads from exhaust fan 45 to metal plate 43, passing through the conveyor opening in barrier segment 38*a* above conveyors 28 and 29. Carrier tubes 46 and 47 extend longitudinally on the sides of frame 16, passing through openings in barrier segments 38*a* and 31*a*in close fit with the inner surfaces of the openings. Carrier tube 46 carries module feed line 17 from supply unit 19, and power lines from control cab 48, to supporting arm member 9; carrier tube 47 carries module feed line 18 from supply unit 19, and power lines from control cab 48, to supporting arm member 10. When plate 43 is in its lowered position, ventilation duct 44 is closed off; when plate 43 is in its raised position, ventilation duct 44 communicates with the space ahead of transverse barrier 31 through the conveyor opening therein.

Stabilizing member 34 has a substantially horizontal platelike upper portion atop two pairs of legs fixedly mounted on opposite sides of frame 16 as in an A-shaped configuration. A side clamping device is mounted on each leg of stabilizing member 34, clamping devices 49 and 50 on a pair of legs on one side of the apparatus, and clamping devices 51 and 52 on a pair of legs on the other side of the apparatus. Each clamping device is comprised of a cylinder mounted on member 34 normal to the length of the apparatus, and having its piston rod pivotally connected to a pad having a serrated outer surface. Two top clamping devices, 53 and 54, are mounted on frame 16, each being comprised of a cylinder vertically mounted on frame 16, passing through the horizontal upper portion of member 34, and having its piston rod pivotally connected to a pad having a serrated outer surface. Actuation of the cylinders in the clamping devices allows the serrated surfaces to be pushed against the sidewalls and ceiling of a tunnel thereby clamping the machine in position when desired.

Two sloping guide members, 55 and 56, are mounted longitudinally on frame 16, one on each side of front conveyor 28 from transverse barrier segment 31*a* forward. Guide members 55 and 56 slope gradually downward toward conveyor 28 and their angle of inclination is adjustable by means of cylinders (not shown). Sloping guide members, 57 and 58, mounted on frame 16 at the forward end of the machine, slope downwardly in the forward direction. Their angle of inclination also is adjustable by means of cylinders (not shown). Guide members 55 and 56 direct rock fragments onto the conveyor, and guide members 57 and 58 direct them into the path of the gathering arms. The angle-adjusting cylinders associated with the guide members are actuated so as to release rock fragments which may become jammed between the machine and the tunnel walls.

The "cylinders" mentioned above are actuated by fluid power and can be hydraulic or pneumatic, hydraulic being preferred on the basis of smaller power package requirements and ease of control.

A typical operation of the apparatus shown in the drawings to advance a geological face in a tunnel according to the process of this invention in rounds comprised of a succession of small drill-load-blast cycles will now be described. The blast pattern for a round is that shown in FIG. 5, and the order of

operations per cycle is that shown in FIG. 6. The machine has 10 drill-and-blast units clustered five to a module "pod," the units operating substantially concurrently in successive 10-hole blast cycles. The total number of holes employed to advance the entire face is 50, and the rounds therefore are 50-hole rounds effected in five successive drill-load-blast cycles at 10 locations per cycle. The amount of condensed secondary explosive loaded into each hole is 1 pound, or 10 pounds per cycle.

With the extension layers around the edges of barrier segments **31***a*, **31***b*, **38***a*, and **38***b* disengaged from the walls, ceiling, and floor of the tunnel, and the serrated surfaces on the pads connected to the cylinders of clamping devices **49**, **50**, **51**, **52**, **53**, and **54** disengaged from the sidewalls and ceiling of the tunnel, the machine is moved to a location before a 100-sq. ft. face such that the operating ends of the drill-and-blast units are about 2 feet from the face, and transverse barrier **31** is about 30 feet from the face. The volume of space between transverse barrier **31** and the face is 300 cu. ft. per pound of explosive loaded per cycle. The distance between the back surface of transverse barrier **38** and the face is 40 feet. The machine is anchored in place by actuation of the cylinders in clamping devices **49**, **50**, **51**, **52**, **53**, and **54**, whereby the serrated surfaces are extended against the ceiling and sidewalls of the tunnel. Cylinders **12**, **13**, **14** and **15** are actuated as required to position supporting arm members **9** and **10** on the required longitudinal axis for the proper axial positioning of modules **1** and **2** to produce the drill hole pattern of cycle **1** (FIG. 5). Modules **1** and **2**, which are substantially coaxial with arm members **9** and **10**, are rotated with respect to the arm members from the unit positions shown in FIGS. **2** and **3** to those of Cycle **1** in FIG. **5**, i.e., module **1** is rotated 90° counterclockwise and module **2** 90° clockwise by energizing motors **126** and **127** (FIG. 4A). This places apertures **7***a* and **7***b*, and apertures **8***a* and **8***b*, on the axes of the holes to be drilled in Cycle **1**. The drilling means, e.g., the drill steels (**92**) and bits (**91**) of rotary percussion drills, of the drill-and-blast units are on these axes. Doors **3***a* and **3***b* of module **1** and **4***a* and **4***b* of module **2** are moved to their open positions, and support means, e.g., drill feed channels (**88**), on which the drilling means in the units are mounted are moved axially out to the face where metal "stingers" (**96**) on the support means firmly engage the face, helping to stabilize the modules when the units' components are extended. With the support means in this position, the drills are moved axially to the face through chain or screw feeds (**87**) driven by air or hydraulic motors, and the drill bits bore holes of the desired depth in the rock by the thrust and rotating action imparted to them by the chain or screw feeds and drill motors (**86**). Rock fragments in the holes are removed by the air from the drills, or flushed out with water.

After the holes have been drilled, the chain or screw feeds act to retract the drills, and the units are indexed, i.e., cylinder **112** is actuated to rotate indexing disc **110** and pivot the units so as to position the explosives delivery hoses coaxially with the holes drilled by the drilling means. The explosives delivery hoses are moved axially and into the drill holes by the action of robot loaders, as described in the aforementioned copending application. After the hoses have been passed to the bottom of the holes, the required amounts of explosive, e.g., number of secondary explosive cartridges, are ejected from the hoses, the explosive being fed to the explosives delivery hoses in feed lines **17** and **18** from an explosives supply means at supply unit **19**, and propelled through the hoses and out of their forward ends in the drill holes by pumping or by compressed air. The delivery hoses are withdrawn from the holes by means of the robot loaders, with repeated light countermovements (tamping), when required, so as to pack ejected cartridges to high density.

After the holes have been loaded with explosive (and explosive tamped, if required), the explosives delivery hoses are retracted by means of the robot loaders, the support means are retracted, and the units are indexed, this time so as to position the guns coaxially with the loaded drill holes. Doors **3***a* and **3***b*, and **4***a* and **4***b*, are moved to their closed positions. Cylinders **37**, attached to hinge plates **36** on barrier segments **31***a* and **31***b*, and cylinders **42**, attached to hinge plates **41** on barrier segments **38***a* and **38***b*, are actuated so that flaps **35** and **40** engage the walls, ceiling, and floor of the tunnel, effecting a seal to attenuate blast pressure and noise levels behind the transverse barriers. Plate **43** is in its lowered position, and front chassis segment **20** is in its retracted position (beneath frame **16**), as shown in solid lines in FIG. **1**. The 10 guns are fired, e.g., by pneumatic or electrical trigger action, a bullet having previously been delivered into the chamber of each gun from a projectile supply means at supply unit **19**, from which the bullets are fed to the projectile delivery hoses in feed lines **17** and **18**, compressed air propelling them forward and positioning them in the gun chambers. Firing of the guns propels a bullet through each aperture in doors **3***a*, **3***b*, **4***a*, and **4***b*, and into the explosive charge in each of the 10 drill holes, detonating the charges and fragmenting the rock surrounding the holes. Immediately after the blast, plate **43** is raised, enabling exhaust fan **45** to draw fumes away from the face and blow them back under positive pressure through ventilation duct **44**; and gathering arms **26** and **27** on apron **24**, the gathering arms on apron **25**, and conveyors **28** and **29** are actuated, front chassis segment **20** being moved to its extended position (dotted lines in FIG. **1**) to enable the gathering arms to clean the floor of the tunnel up to the face. Fresh air moves toward the face through the conveyor openings in barrier segments **31***a* and **38***a*, and/or through air feed ducts capable of being opened and closed. Supporting arm members **9** and **10** and modules **1** and **2** are repositioned for the Cycle **2** drilling step (FIG. **5**), apertures **7***a* and **7***b*, and **8***a* and **8***b* being placed on the axes of the holes to be drilled in Cycle **2**. In this cycle, since one module operates at the bottom of the face, front chassis segment **20** is retracted beneath frame **16** (solid lines in FIG. **1**) and the operation of gathering arms **26** and **27** interrupted during the positioning and operation of the modules. Module **1** is rotated clockwise 90° and tilted downward, and arm member **9** is lowered and swung to the left; while module **2** is rotated clockwise 90° and tilted upward, and arm member **10** is raised and swung to the right. The drill-and-blast units are indexed so as to position the drills on the axes of the holes to be drilled in Cycle **2**, doors **3***a*, **3***b*, **4***a*, and **4***b* are reopened, and Cycle **2** is continued with the same sequence of operations as in Cycle **1**. As is shown in FIG. **6**, ventilation at the face continues until the blast step of the cycles, immediately prior to which fume exhaustion and fresh air feed are interrupted by lowering plate **43**, and closing the doors in the air feed ducts, if present. Immediately after the blast step of the cycles, mucking and ventilating operations resume.

Cycles **3**, **4**, and **5** follow Cycle **2** consecutively with the same sequence of operations as in Cycle **1**, the supporting arm members and modules being repositioned before each new cycle to give the drill hole pattern shown in FIG. **5**. In Cycles **3** and **4**, front chassis segment **20** remains extended and the gathering arms and conveyors continue to operate during the drill and load steps, as is shown in FIG. **6**. In Cycle **5**, the modules operate at the bottom of the face and therefore, as in Cycle **2**, front chassis segment **20** is retracted and the operation of gathering arms **26** and **27** interrupted during the positioning and operation of the modules.

In the blast step of each cycle, the majority of rock fragments fall ahead of transverse barrier **31**. With 100 percent tunnel closure provided by transverse barriers **31** and **38**, or about 95–100 percent closure provided by transverse barriers **31** and **38** plus one or two like transverse barriers mounted behind barrier **38** in tandem, the sound pressure level in the zone behind the rearmost barrier is below 140 decibels, a limit set by law for human tolerance.

The excavation apparatus of the present invention has a plurality i.e., two or more, of drill-and-blast units which enable it to advance a face in cycles of multiple sequences. The multi-

ple units can be housed each within a separate single-unit module, i.e., in a module comprising a single drilling means, single explosives delivery means, and single energy-delivering means, suitably supported and housed; or multiple units can be clustered within a common housing member in a composite module or pod as illustrated in FIGS. 4, 4A and 4B. The apparatus can have a single composite module, multiple single-unit modules, multiple composite modules, or a combination of single-unit and composite modules. Multiunit composite modules are preferred over single-unit modules because they offer the advantage of greater efficiency with respect to space and weight utilization. The apparatus can have a single supporting arm member with all of the modules mounted thereon (one or more); or multiple supporting arm members each with a single module, each with multiple modules, or one or more bearing a single module and one or more others bearing multiple modules. Multiple arm members can together support a single module.

The specific number of drill-and-blast units, modules, and supporting arm members, and the distribution pattern of the units with respect to multiple modules, and of multiple modules with respect to supporting arm members therefor, can vary. The number of units in the module(s) and the number of modules mounted, or mountable, in the apparatus determines the maximum number of holes which can be worked on per cycle or, in other words, the number of locations at which a group of drill-load-blast sequences can be carried out concurrently (e.g., drill at all of the selected locations substantially simultaneously, then load at all of the locations substantially simultaneously or in rapid succession, followed by a break in the blasting to begin the drill step of the next cycle). Thus, to be capable of the highest possible rate of advance with a given size of explosive charge in the drill holes, it is desirable to have the largest possible number of units per module, and the largest possible number of modules mounted, or mountable, in the apparatus as can be supported satisfactorily, operated freely, and serviced conveniently, in the contemplated work space, while the size of the cycles is kept small enough that the pressure capability of the machine is not exceeded. Preferably, as many of the drill-and-blast units in the apparatus as possible are operated in every cycle, although not every unit need be operated in every cycle. Furthermore it is not necessary that the capacity of an apparatus for mounting modules be utilized fully in all operations, the apparatus being capable of operating with fewer or more modules as may be required with a changing blast pattern or changing conditions. Considering as a typical case the advancement of a 9-foot-wide by 9-foot-high tunnel face with about 20–50 holes per round, an apparatus having at least about two, and up to about 25 drill-and-blast units, usually is suitable, with about four to 12 being preferred, the larger numbers of units being used as the number of holes per round is greater, space permitting. With a larger tunnel face, 50 or more units may be employed. To provide greater versatility with respect to changeability of blast cycle patterns, it is preferred that at least two multiunit modules or pods be employed, in any suitable distribution pattern, e.g., a two-to 10 -unit module together with a second two-to 10-unit module, the number of units in one module being the same or different than the number of units in the other(s). The geometric arrangement or cluster pattern of the units within a composite module or pod can vary as required. Linear (straight or curved) or polygonal clusters of units can be employed for working in linear or polygonal drill-hole patterns.

The specific number of supporting arm members in the apparatus is selected chiefly on the basis of the number of modules and drill-and-blast units in the modules, and the available working space. In the preferred apparatus wherein there are two or more multiunit pods, it is preferred to have a single module per supporting arm member. Thus, considering versatility as well as expected space limitations, a preferred apparatus is one having one to eight supporting arm members, each having a single multiunit module mounted thereon.

The apparatus of this invention operates with its front end confronting a generally vertical face to be advanced. The forwardmost components of the apparatus are the fragment-collecting means, associated with the front end of the lower supporting frame or chassis of the carriage, and the drill-and-blast modules(s), the front end(s) of which confront the face, followed by the supporting arm member(s) for the module(s), the module(s) and arm member(s) adopting a normal or oblique attitude (front-to-back dimension) with respect to the vertical. The apparatus is stationed before the face during every operation of the drill-load-blast cycles. Therefore, all components of the apparatus are capable of withstanding the effects of fly rock or air blast to which they will be exposed. The chassis and associated fragment-collecting and transporting means are of sufficiently rugged construction to withstand these effects. All components of the drill-and-blast units, including motion-imparting mechanisms therein, power supply lines, mechanisms, and joints associated with the supporting arm member(s), the control means, the ventilation means, and the explosives supply means and feeding means (and projectile supply means and feeding means, if the energy-delivering means are guns) are protected from blast pressure and fly rock by shielding means. The shielding means comprises armored housing on the supporting arm member(s) and module(s), and at least one transverse barrier, e.g., a metal platelike member mounted on the carriage with its large-area surfaces substantially parallel to the face, the transverse barrier being located behind the supporting arm member(s) and module(s) and forward of the explosives supply means and, if present, the projectile supply means. "Armored housing" on the module(s) and supporting arm member(s) denotes an outer shell or covering capable of withstanding air blast and impact effects. Such shells protect the module components, motion-imparting mechanisms, power lines, e.g., hydraulic, pneumatic, and electrical lines, and mountings from the blast e.g., Except where flexibility is required of the housing, e.g., at movable joints, the housing is rigid and usually metallic. The closure member at the operating end of the armored module is adapted to be opened to permit axial extension and operation of the drilling and loading means, and to be closed during the blast step when the axially extendable members are in the retracted position and the energy-delivering means is to be actuated. The closure member has an aperture or porthole therein for each drill-and-blast unit in the module "pod," each porthole being on an axis on which the initiating energy is to be delivered to initiate a condensed secondary explosive charge in a drill hole. The mechanical means employed to achieve opening and closing of the closure member is not critical. In one embodiment, the module has a swingable closure member, e.g., in the form of one or more doors, which form one or more openings at the operating end when swung open, permitting extension of all required components. This type of opening affords front access to the module components, when required, and therefore is preferred. On the other hand, it is also possible to provide a local opening for each drill-and-blast unit in the closure member, with means for narrowing the relatively large opening required for operation of the drilling and loading means to the size required for delivery of the initiating energy. Although the configuration of the supporting arm and module outer shell or housing is not a critical feature, a conical or wedge-shaped operating-end-closure configuration on the modules is preferred as a means of providing added protection against rock impacts, this design resulting in a greater degree of glancing rock impact. For the same reason, sloping surfaces on the arm and module outer shell are preferred. Greater protection against rock impact can be provided along the leading edge of the module by a "bumper"-type member (e.g., **5** in module **1**, and **6** in module **2**, in FIGS. **1**, **2**, **3**, **4**, and **4A**) made, for example, of hard rubber or a tough, hard metal, e.g., Stellite.

The configuration and dimensions of the supporting arm member(s), their mounting location on the carriage, their attitude and mobility with respect to the carriage, and the con-

figuration and dimensions of the structural member(s) or framework on the carriage to which the back end of each arm member is secured can vary widely, depending on such factors as the configuration and weight of the module(s) to be supported and maneuvered, the dimensions of the face to be advanced, the type of arm maneuverability required to carry out drill-load-blast cycles of the desired patterns with a given combination of drill-and-blast units, the size of the blasts, etc. As a rule, however, the arm members will be cylindrical, of any convenient cross-sectional configuration, and preferably will be long enough, i.e., mounted on the carriage sufficiently far back, that an inordinate degree of arm lift is not required for repositioning of the module(s) to achieve a desired blast pattern. For many situations, adequate capability is achieved when the arm(s) are secured at their back ends to the machine carriage in a generally horizontal attitude and are capable of lifting to a position of about 15° above the horizontal and lowering to a position of about 15° below the horizontal. Preferably, the arm(s) also have the capability of swinging to the right and left, e.g., to positions of about 15° on opposite sides of a line normal to the face. Modest angles of lift and swing are preferred because they permit the use of less-flexible power lines, i.e., pneumatic and hydraulic hoses, and provide less impact surface to fly rock.

The type of mounting for the supporting arm member(s) on the carriage, and the location and design of the mechanisms for moving the arm member(s) are not critical provided they afford the required support for the module(s) and repositioning capability. Double pivot or double clevis mounting with swing and lift hydraulic cylinders associated with the mounting can be employed. Another type of construction is a spherical segment mounting (modified ball joint allowing passage of power and feed lines) of the back of the arm to the carriage, and an arm-positioning device attached to the carriage floor and to the under portion of the arm member at a forward location near the module (as shown in FIGS. 1 and 3). The positioning device can consist of two cylinders preferably forming a triangle with the floor between them, the arm being secured to the two cylinders at the apex angle formed by the cylinders. Alternatively, the supporting arm member can be positioned by means of a screw actuator, which is a preferred device for the reason that the position of the arm can be monitored more readily therewith. The arm-positioning devices preferably are shielded from fly rock, e.g., by a surrounding skirt shield or a vertical bumper.

The module is pivotally and rotatably secured to the front end of the supporting arm member, with its operating end forward and generally on about the same longitudinal axis as the arm member. The module is adapted to rotate with respect to the axis of the arm member, e.g., through an angle of up to about 360° , as well as to tilt upward and downward, e.g., through an angle of up to about 15° in each direction. Such motion capabilities allow the drill-and-blast units in a composite module to operate on different sections of the face with alteration of the positioning of a given group of drill holes with respect to the axis normal to the face, and permit the components of the units to be positioned as close to the periphery of the face as possible.

The motion capabilities of all supporting arm members and modules can be substantially the same, or different. For example, the apparatus can have one or more central arm members and modules in fixed positions, and peripheral arm members and modules movable as described above. A preferred apparatus, however, on the basis of versatility, is one in which all arm members and modules are movable.

The specific nature of the working components of the drill-and-blast units can vary, e.g., as described in the aforementioned copending application. With respect to the drilling means, for example, mechanical drilling means, such as percussion drills or hammers, rotary drills, or rotary percussion drills; drilling means employing high-pressure fluids, such as abrasive-laden hydraulic jets; or thermal drilling means employing hot gas or flame jets, electrical disintegration, electron beams, or lasers; or any combination of such drilling means can be employed in the units. The energy-delivering means preferably is a means of projecting propagative energy to the charge through an inactive medium, i.e. energy which derives from the intensity and time dependence of the dynamic physical phenomena utilized to transport it from one place to another, e.g., the energy which derives from the intensity and time dependence of an electromagnetic field or of shock wave pressure, the velocity of a projectile, etc. Projectile-propelling devices (guns), lasers, and high-energy electrical discharge devices in combination with electrode-feeding means are examples of such energy-delivering means. Means for conveying and positioning a blasting cap, e.g., of the instantaneous type, in the drill hole in contact with the condensed secondary explosive charge therein and subsequently actuating the cap also can be employed as the energy-delivering means, but such means may not be preferred because of the risk of accidental detonation due to the presence of a primary explosive charge in a continuous reaction train with the secondary explosive charge in the drill hole when the cap has been positioned therein.

The exact nature of the mounting structure for the drill-and-blast units is not critical provided the structure allows the components to move freely as required, and to withstand the effect of shock of the magnitude which will be encountered in use. A solid mounting block with suitable longitudinal apertures or slots for receiving the units can be employed. A lighter weight structure which can be used consists of two or more transverse platelike supports (as in FIG. 4A) fixedly attached to the module housing, the working components of the units fitting in corresponding apertures or slots in the platelike supports. The design of the cross section of the support structure normal to the module axis can vary from a comparatively open design, e.g., a central disclike portion with radial spokes emanating therefrom and fixed to the housing wall, the units being mounted radially on the central portion between spokes; to a more closed design, e.g., one in which a cutout or open portion of the cross section is substantially no larger than that needed to fit the units and permit their required indexing motion. The use of the structure shown in FIGS. 4, 4A, and 4B is a preferred one in that the bulkhead-type platelike supports, if thin enough to flex in the direction of the module axis, afford a means of uncoupling the housing wall from the axial shock, reducing the shock effect on the module components. Also, the comparatively closed design in the transverse direction provides a certain degree of protection against the entry of duty from the front end of the module.

The powered carriage of the apparatus of this invention is comprised of a movable chassis, or lower supporting frame, and a body set thereon. The carriage has a forward end which confronts the face to be advanced, the face being substantially normal to the direction of the apparatus' travel, i.e., the direction of the carriage's traction propelling devices. The supporting arm member(s) and module(s) extend in the same general direction as the carriage's traction propelling devices. The front end of the chassis is formed into a loading apron or deck, which forms a part of the fragment-collecting means. The apron is adapted to contact the ground surface ahead of the assembly and slopes downwardly to the ground at its forward end. Mounted on the apron, one at each side thereof, are two gathering arms which operate with a sweeping motion to gather the fragments, e.g., rock pieces, from the ground area immediately ahead of the apron. The module(s), which are suspended above the apron and gathering arms, extend forward beyond the latter so that the module units can work on the bottom portion of the face. A fragment-transporting means, e.g., an endless conveyor, is mounted on the chassis on an axis which is substantially equidistant from the axes of rotation of the gathering arms, and extends front-to-back from the gathering arms to a discharge location. The material gathered by the arms is crowded onto the forward end of the conveyor, which transports the material rearwardly to be discharged from the apparatus. Additional fragment-removing capability

can be achieved with an apparatus having two or more pairs of gathering arms, each pair with an associated conveyor, mounted side-by-side on the same separate aprons.

The design of the portion of the carriage which is set on the chassis is not a critical feature of the apparatus provided it allows the gathering arms, conveyor, and module-supporting arm members to operate as required, and permits rock to fall onto the conveyor. In one design, e.g., that shown in FIGS. 1 and 2, the body portion of the carriage is essentially a single-level framework with appropriate mounting surfaces for the supporting arm member(s), barrier(s), etc., multiple supporting arm members being mounted at substantially the same level. In an alternate design, the body portion can be a multilevel framework or gantry, which design allows supporting arm members to be mounted at different levels, e.g., two arm members per level.

In a preferred apparatus, the surfaces exposed to fly rock are disposed at angles oblique to the horizontal, e.g., 45° or less (nonpenetrating angles for horizontal rock motion). Also, the exposed surfaces of the carriage adjacent to the conveyor preferably slope gradually downward from the sides of the carriage inward to the conveyor, thereby directing the rock fragments onto the conveyor. Further, any exposed surfaces of the upper portion of the carriage at the front end of the apparatus preferably slope downwardly in the forward direction to guide fly rock into the path of the gathering arms. Adjustable sloping guide members are preferred, since raising of the guide members at the sides of the apparatus changes their angle of inclination and the distance between the apparatus and the tunnel walls, allowing the release of any rock fragments which may become jammed between the apparatus and tunnel walls.

In order that the gathering arms may collect all of the fragments in the path of the apparatus, the arms must be able to move ahead toward the face as they work. This may be accomplished by moving the entire apparatus forward, to the extent allowable by the supporting arm member(s). It is preferred, however, that there be a relative forward and backward motion capability between the frame or deck on which the gathering arms are mounted and the upper portion of the carriage on which the supporting arm member(s) and module(s) are mounted. This allows the gathering arms to take up alternately extended and retracted positions with respect to the upper carriage portion, providing more effective mucking and also affording a measure of protection to the gathering arms during the blasts by permitting their retraction under the carriage. The supporting arm member(s) can be caused to move back with respect to the gathering arms by having the upper portion of the carriage mounted on rails, for example. Alternatively, the chassis can have a front frame segment, i.e., that segment containing the front loading deck, gathering arms, and associated conveyor, which is independently axially movable with respect to the body portion of the carriage and with respect to one or more rear chassis frame segments so that it can move to an extended forward position for mucking while the drill-and-blast units are working at middle and upper levels on the face, and to a retracted position while the module units are working near the bottom of the face.

The chassis is propelled by suitable traction devices, preferably crawlers or tractor treads, and, when required, two or more sets of traction devices, axially aligned, may be employed. In a particularly preferred embodiment, redundance is incorporated in the fragment-collecting means by providing one or more additional pairs of gathering arms behind a front pair as an extra measure of insurance that fragments do not remain in the travel path of the back part of the machine. A chassis of this type having front and back crawlers, and front and back gathering arm loaders, all loaders communicating with a conveyor, can be constructed, for example, by suitably combining two or more commercially available crawler-mounted gathering arm loaders, e.g., 14 BU-10 Loaders, made by the Joy Manufacturing Company. The loaders can be aligned one behind the other with the front end of a back loader fitting under the back end of the conveyor associated with the loader ahead of it, the conveyors all communicating with one another.

The explosives supply means, projectile supply means (if present), ventilation means, and control unit for the apparatus are located behind one or more transverse barriers. The barrier not only protects these components of the apparatus from impact by fly rock which may reach them, but acts as a pressure- and sound-attenuation shield, intermittently sealing off the space ahead of the barrier(s) so that blast pressure and noise levels in a zone behind the barrier(s) are within prescribed safe limits of human tolerance. The barrier, or combination of barriers, constitute an environmental transition region wherein blast pressure and noise are attenuated. Each transverse barrier comprises a rigid, platelike member having edge portions which are extensible and retractable in directions substantially normal to the edge surface(s) thereof. The term "platelike member" as used herein to describe the transverse barrier is descriptive of the overall geometry of the member, i.e., a member having two opposing boundary surfaces of large dimension(s) relative to the dimension normal thereto, rather than of the structural makeup of the member. The term is meant to include a single-unit structure, e.g., a single plate, slab, or disc, as well as multiunit structures, e.g., two or more subplates in adjacent end-to-end position (i.e., with the corresponding broad surfaces of the subplates adapted to be substantially coplanar) or in offset end-to-end position (i.e., with the subplates adapted to be in substantially parallel, noncoincident planes). With multiplate structures, there is substantially no free space between the two adjacent or nearest end surfaces of each pair of subplates in the structure, and therefore there is an intervening (usually substantially horizontal) rigid member such as a plate or slab between the two nearest end surfaces of all spaced-apart pairs of plates. Also, in multiplate structures, although the subplates are adapted to be in substantially parallel planes, one or more of the subplates can be adapted to move so that an angle can be present between a pair of subplates. Preferably, each transverse barrier is adapted to have its vertical dimension increased or decreased so that the apparatus can be used in excavations of various sizes. For example, the barrier can comprise a lower subplate fixedly mounted substantially vertically on the carriage and an upper subplate adapted to pivot about a horizontal axis to enable it to be moved from the vertical position as required. Furthermore, the platelike member can have a laminar structure of side-by-side adjacent layers in vertical planes parallel to the large-dimensioned boundary surfaces of the member, e.g., layers of different materials such as a layer of granular material or corrugated metal between two solid metal plates.

The edge portions of the platelike member are extensible and retractable to adapt the barrier to engage and disengage the walls, ceiling, and floor of a tunnel as a seal. For example, the edge surfaces of the barrier plate(s) can be surrounded by an expandible, e.g., rubber, collar or hose. The collar is adapted to extend to the tunnel surfaces as a result of expansion when inflated, and to retract from these surfaces as a result of contraction when deflated. In another type of sealable barrier, a bladderlike layer is attached edgewise to the barrier plate(s) at or near the edges thereof. The bladderlike layer hangs limp and therefore disengaged from the tunnel surfaces when unpressurized, and rigid and erect and in engagement with the tunnel surfaces when pressurized with fluid. Alternatively, the extensibility and retractability of the sealing layer can be achieved mechanically by use of a hinged flap or wedge layer of a heavy elastomeric material, mounted near the edge surfaces of the barrier plate(s), the flap or wedge being extended to, and pressed against, the tunnel surface and retracted therefrom, for example, by the actuation of cylinders connected to metal hinge plates fastened to the flap or wedge.

Since the tunnel surfaces are apt to be irregular, maximum sealing potential is afforded by a barrier having an edge layer adapted to extend out to the tunnel surfaces to varying

degrees from location to location along the layer's length. With such a layer, the amount of extension employed from section to section can conform to that required by the distance between the section and the tunnel surface. Such a capability can be provided, for example, with a hinged elastomeric flap or wedge having a sufficient number of independently actuatable hinge plates to move sections of the flap as required to seal the tunnel. In another embodiment, the extensible-retractable sealing layer can be sectionalized in the direction of the layer's length, each section of the layer being variably extensible and retractable. One type of sectionalized layer which can be used consists of bladderlike members positioned adjacent each other around the edge surfaces of the barrier plate(s) in the nature of a sectionalized collar. The collar sections can be inflated and deflated independently to the degree required by the surrounding tunnel surface. Alternatively, a number of flexible hoses can be attached at one end to the barrier plate(s), the hoses being adjacent each other and hanging limp when unpressurized, and rigid and erect when pressurized with fluid. With sectionalized inflatable layers, it is advantageous to use two or more adjacent layers with the sections of one layer staggered with respect to those of the next to assure optimum sealing. The hinged flap or wedge seal layer described above also can be sectionalized with each flap or wedge section movable via a separate metal hinge plate, e.g., as is illustrated in FIGS. **1**, **2**, and **3**. Overlapping of adjacent flaps, and/or the use of two or more adjacent layers with the flaps of one staggered with respect to those of the next, can be employed for optimum sealing. The flap or wedge type of seal is preferred since it is more rugged than the inflatable seals, being less prone to failure as a result of accidental cutting on rock. The barrier engages the surrounding surfaces during blast, and is disengaged when movement of the apparatus is required. Also, all openings in the barrier(s) which permit communication between the external environments ahead of and behind the barrier(s) are adapted to be closed off during blast, and opened during the remaining steps of the drill-load-blast sequences. Two or more transverse barriers mounted on the carriage in tandem are preferred to provide maximum pressure and noise reduction capability. With two or more transverse barriers, each barrier can have its own closure means for the opening(s) therein, e.g., sliding or pivotable doors, or the openings in the different barriers may be joined together by a duct and the duct shut off at the opening in the front barrier.

In a preferred apparatus, the distance between the transverse barrier (i.e., a single barrier, or the forwardmost of multiple barriers) and the face during operation of the apparatus is great enough, that most of the fragments propelled back from the face fall in front of the barrier, the falling fragments being guided onto a conveyor by the sloping exposed surfaces of the carriage (**55** and **56** of FIG. **2**) and the gathering arms of a back gathering arm loader (e.g., the arms on deck **25** of FIG. **1**). Having the barrier set back from the face in this manner is advantageous not only because the effect of repeated impact on the barrier is avoided, but also because the pressure exerted on the barrier, and therefore the pressure to be attenuated by the barrier(s), is lower owing to the larger volume of space ahead of the barrier. To facilitate pressure- and sound-attenuation with blast cycles of an economically acceptable size, the location of the transverse barrier(s) should be such as to provide between the barrier(s) and the face (i.e., between the environmental transition region and the face) a volume of at least about 150 cubic feet per pound of condensed secondary explosive detonated per cycle. The zone of reduced pressure and noise levels behind the transverse barrier(s), i.e., behind the environmental transition region, is the zone where personnel may be located. The distance between this zone and the face depends on the number and positioning of transverse barriers on the carriage, but generally is no more than about 100 feet, and usually no more than about 50 feet.

Each drill-and-blast unit in each module in the apparatus includes an axially movable forward end portion of an explosives delivery hose in communication with an explosives feeding means, the latter communicating also with an explosives supply means. The explosives supply means is mounted either on the same carriage as the transverse barrier(s) or trails the barrier(s) on a separate carriage. The type of explosives supply means and feeding means depends on the nature of the explosive. For example, the supply means can be a magazine containing cartridged explosive or bulk solid explosive, or one or more storage tanks for slurry explosive ingredients. The feeding means can be, for example, pneumatic loaders for solid explosives, or pumps for slurry explosives. The feeding means has loading tubes or delivery hoses which terminate in drill-and-blast units. For loading cartridged explosives, e.g., dynamites, preferred feeding means are pneumatic cartridge loaders such as are described in U.S. Pat. No. 3,040,615 and in *The Modern Technique of Rock Blasting*, V. Langefors and B. Kihlstrom, Stockholm Almqvist & Wiksell, 1967, pp. 97–101. With the pneumatic cartridge loader, a semiautomatic breechpiece can be used to feed cartridges continuously. The tubes or hoses leading from the feeding means to the drill-and-blast units are somewhat flexible and can be made, for example, of metal or plastic. All of the explosives delivery hoses can be housed within a common feed tube for passage through the apparatus, as shown in FIGS. **1** and **2**, preferably in a manner such that each individual hose is free to move independently in an axial direction with no effect on neighboring hoses. The reason for this preferred condition is that the operation of the working components of a given drill-and-blast unit, including the axial extension and retraction of the explosives delivery hose, preferably is controllable independently of the operation of the components of other units. This permits the operation of less than all of the units in a given cycle, the drilling of holes of different depths by a given group of units, the loading of different amounts of explosive in the different holes by a given group of units, etc.

When the energy-delivering means of the units are guns, projectile supply means is mounted either on the same carriage as the transverse barrier(s) or trails the barrier(s) on a separate carriage. The projectile supply means, e.g., a magazine, communicates with feeding means, such as the pneumatic loaders mentioned above, the latter having tubes or hoses leading to the chambers of the guns.

The mechanisms (actuators and sensors) in the machine for cooperatively moving and positioning the various components thereof in a preselected overall pattern, e.g., that shown in FIG. **6**, are energized by power transmission thereto from a control unit or center in a control cab located behind the transverse barrier(s). The control unit can be located on the same carriage as the supporting arm member(s) and transverse barrier(s), as shown in FIGS. **1** and **2**, or it can trail behind on a separate carriage.

The apparatus can have a face-illuminating means, i.e., a light source adapted to be focused on the face, and a viewing port through which the face can be viewed directly. Alternatively, or in addition, indirect face-sighting means, e.g., a closed-circuit television camera mounted behind a transverse barrier at a port therein can be incorporated in the machine, the port being adapted to be closed when the energy-delivering means of the module units are operating. Air blowers can be mounted in the modules and operated when needed to clear dust away from the face and thus assist visibility.

The apparatus of the invention performs all of the operations required to advance a face by drill-and-blast, including the initial cut. No mechanical cutting means are required. In carrying out the process of this invention, the location, pattern of the groups of drill-and-load-blast sequences (hole pattern), the time pattern in which the groups of sequences are performed, the number of sequences carried out concurrently (holes per cycle), and the amount of explosive detonated per cycle are all conditions that can vary widely and independently, depending on many factors such as the overall size of the face, the physical properties of the material being excavated, the number of drill-and-blast units available, the mo-

bility of the units, the degree of constriction of the working area, ventilation and noise abatement requirements and capability, etc. In most cases the size of the cycles will be about 5–50 percent of the size of the entire round, most often up to about 35 percent of the total number of holes required, or such that no more than about 100 pounds, usually up to about 30 pounds, of explosive detonates per cycle.

The angle of the drill holes with respect to the face may vary. In some instances, the holes will need to be drilled non-normal to a face be cause of space restrictions at the sides, ceiling, and floor of a tunnel. In other instances, oblique holes will be used to provide a special type of cut. Also, the length of the explosive charges in the holes of a given cycle can be substantially uniform or different. Variations in angle and/or explosive charge length from hole-to-hole may be employed in some cycles and not in others, but they are used more often in the first cycle (e.g., Cycle 1 in FIG. 5), in which the opening cut is made. Any of the patterns commonly employed in drill-and-blast operations can be employed in the present process. In a given cycle, the explosive charges in all holes can be detonated substantially simultaneously, or a small delay can be used between detonations in individual holes or groups of holes. When delays are employed in a given cycle, they should be short enough that fly rock produced by detonation in a given hole or group of holes is not propelled from the hole(s) before the initiating energy is delivered to the explosive charge(s) in the adjacent hole or group of holes. As a rule, any delay between detonations in adjacent holes or groups of holes is no more than about 3 milliseconds per foot of distance between the holes or groups of holes. In the blast cycle pattern shown in FIG. 5, for example, the explosive charges in the groups of holes at the periphery of the face in some or all of the peripheral cycles (2, 3, 4, and 5) may be detonated at some small interval after the charges in the groups of inside holes, i.e., those closer to the opening in the face made in Cycle 1, e.g., an interval of about 1–6 milliseconds when the spacing between the peripheral groups and inside groups is about 24 inches or less.

The overall sequential pattern of operations performed in each cycle in the process of this invention is that of drill, load, and blast, with pressure and noise attenuation after blast and with mucking and ventilation during the drill and load operations, except in cycles in which the holes being drilled and loaded are at the bottom of the face. In the latter cycles, mucking begins immediately after the blast step of the previous cycle and is interrupted before the module(s) are repositioned. Ventilating operations proceed continuously except during the blast step. Within this overall pattern, certain specific operations can be performed substantially simultaneously, as shown in FIG. 6, e.g., the positioning of the supporting arm member(s) and module(s) and opening or closing of module doors and shield opening(s). Others are sequential, e.g., opening of module doors before the extension of drill feed channels and drills to the face; retracting of explosives delivery hoses before closing of module doors; closing of module doors and shield opening(s) before the blast step; and opening the barrier seal before repositioning the machine. Because the apparatus remains at the face during the entire succession of cycles constituting a round, and many of the operations are performed simultaneously, the drill-load-blast sequences and the succession of cycles are substantially continuous. Typically, the total "dead time" per sequence, i.e., the time between drilling and charge placement steps plus the time between charge placement and charge initiation steps, is on the order of 0.25 minute or less; while the "dead time " between cycles is less than about 0.25 minute. The total time elapsing per round depends chiefly on the number of holes to be drilled and loaded. A round carried out in the blast cycle pattern shown in FIG. 5 with 3-foot-long holes loaded with dynamite cartridges, for example, is performed in about 11 minutes.

We claim:

1. An excavating apparatus for advancing a subsurface face in a geological formation comprising:

a. a powered carriage having a forward end which confronts a face to be advanced;

b. at least one supporting arm member pivotally mounted at its back end on said carriage;

c. a plurality of drill-and-blast units positioned in at least one drill-and-blast module, said module being pivotally and rotatably mounted on the front end of a supporting arm member, said drill-and-blast units comprising (1) drilling means, (2) means for delivering a charge of condensed secondary explosive into a hole made by said drilling means, and (3) means for delivering energy to said secondary explosive charge in said hole to initiate said charge;

d. explosives feeding means including explosives delivery hoses each of which has a forward end portion terminating in a drill-and-blast unit, said explosives feeding means being in communication with explosives supply means and adapted to deliver explosive material from said explosives supply means, through said explosives delivery hoses, and out of the free forward ends of said hoses when the latter are in communication with drill holes;

e. means mounted on said carriage for collecting and transporting solid fragments, said collecting means being adapted to move fragments to said transporting means from the path of the apparatus at the forward end of said carriage, and said transporting means from the path of the apparatus at the forward end of said carriage, and said transporting means being adapted to move fragments away from the apparatus;

f. ventilation means adapted to draw airborne fumes away from the face and cause fresh air to move up to the face; and

g. shielding means adapted to protect components of the apparatus from blast pressure and rock impact, said shielding means comprising (1) at least one transverse barrier mounted on said carriage behind said supporting arm member and drill-and-blast module and forward of said explosives supply means and being adapted intermittently to engage the surrounding surfaces of an underground opening as a seal, and (2) armored housing on said supporting arm member and said module; said transverse barrier having at least one opening therein through which (A) said fragment-transporting means extends so as to communicate with said fragment-collecting means at the forward end of said carriage, (B) said explosives delivery hoses extend so as to terminate in said drill-and-blast units, and (C) said ventilation means extends to the space between said ventilation means and the face, all openings in said transverse barrier which permit communication between the external environments ahead of and behind said transverse barrier being adapted to be closed off intermittently.

2. An apparatus of claim 1 wherein said means for delivering energy to said secondary explosive charges in said holes are guns, and projectile supply means is located behind said transverse barrier and in communication with projectile feeding means including projectile delivery hoses, each of which passes through an opening in said transverse barrier and communicates with the chamber of a gun in each drill-and-blast unit, said projectile feeding means being adapted to deliver a projectile from said projectile supply means, through said delivery hoses, and into said gun chambers.

3. An apparatus of claim 1 wherein a plurality of supporting arm members are mounted on said carriage, and a drill-and-blast module containing a plurality of drill-and-blast units is mounted on each of said supporting arm members.

4. An apparatus of claim 3 wherein said module units are arranged in the form of a polygon.

5. An apparatus of claim 1 wherein the location of said transverse barrier on said carriage is such that the majority of dislodged fragments propelled toward said barrier from the face fall forward of the barrier.

6. An apparatus of claim 5 wherein the location of said transverse barrier on said carriage is such as to provide

between said transverse barrier and the face a volume of at least about 150 cubic feet per pound of condensed secondary explosive delivered into holes substantially concurrently by said drill-and-blast units.

7. An apparatus of claim 1 wherein said transverse barrier has a lower segment fixedly mounted on said carriage and an upper segment pivotally secured to the upper edge of the lower segment to enable the upper segment to pivot about a horizontal axis.

8. An apparatus of claim 1 wherein said ventilation means includes at least one duct which communicates with the space between a transverse barrier and the face through an opening in said transverse barrier and is adapted to be closed intermittently.

9. An apparatus of claim 1 wherein openable closure means are mounted adjacent all openings in said transverse barrier which permit communication between the external environments ahead of and behind said transverse barrier.

10. An apparatus of claim 1 wherein a plurality of transverse barriers are mounted on said carriage in tandem, said fragment-transporting means and said explosives delivery hoses pass through all of said transverse barriers, and said ventilation means includes a duct which communicates with the space between the forwardmost transverse barrier and the face and which passes through all other barriers, said duct being adapted to be closed intermittently.

11. An apparatus of claim 10 wherein the location of said forwardmost transverse barrier on said carriage is such that the majority of dislodged fragments propelled toward said barrier from the face fall forward of said barrier.

12. An apparatus of claim 1 wherein the chassis of said carriage has a front frame segment and at least one rear frame segment, each of said frame segments bearing fragment-collecting and fragment-transporting means, said front segment being adapted to move forward and backward independently of the body portion of said carriage and other frame segments.

13. An apparatus of claim 12 wherein each of said frame segments of said chassis is mounted on a separate pair of spaced crawlers and each frame segment bears a fragment-collecting means communicating with a fragment-transporting means, the fragment-transporting means on all of said frame segments communicating with each other.

14. An apparatus of claim 1 wherein said fragment-collecting means is a plurality of gathering arms and said fragment-transporting means is an endless conveyor.

15. An apparatus of claim 1 wherein surfaces forward of a single transverse barrier, or of the forwardmost of a plurality of transverse barriers, are disposed at angles oblique to the horizontal, and said surfaces which are adjacent to the fragment-transporting means slope downward from the sides of said carriage inward to said fragment-transporting means.

16. An apparatus of claim 15 wherein said surfaces which slope downward to said fragment-transporting means from the sides of said carriage are surfaces of adjustable guide members, said guide members being adapted to have their angle of inclination changed so as to change the distance between said guide members and the neighboring side surfaces of an underground opening.

17. A process for advancing a subsurface face in a geological formation comprising:

a. performing a substantially continuously succession of groups of substantially continuous drill-load-blast sequences, each of said sequences at a single location in the face different from the locations therein where other sequences are performed, the sequences in each of said groups being carried out substantially concurrently, and each sequence comprising the steps of (1) drilling a hole in the face, (2) placing a charge of condensed secondary explosive in said hole, and (3) delivering energy to said secondary explosive charge in said hole in a manner such that energy is released into said charge at a rate sufficiently high to cause detonation thereof;

b. concurrently with steps (a)(1) and (a)(2), removing from the vicinity of the face dislodged fragments and airborne fumes produced during Step (a)(3) of the previous group of sequences; and

c. attenuating blast pressure and noise in an environmental transition region behind the face, to the extent that the blast pressure and noise levels in a zone behind said region are within prescribed safe limits of human tolerance.

18. A process of claim 17 wherein energy is delivered to said secondary explosive charge in each sequence by propelling a projectile into said charge.

19. A process of claim 17 wherein the location of said environmental transition region is such as to provide between said region and the face a volume of at least about 150 cubic feet per pound of condensed secondary explosive placed in holes in each substantially concurrent group of drill-load-blast sequences, said zone behind said transition region being up to about 100 feet from the face.

20. A process of claim 17 wherein, in each group of substantially concurrent drill-load-blast sequences, step (a)(1) is performed in all sequences substantially simultaneously, step (a)(2) thereafter is performed in all sequences substantially simultaneously, and step (a)(3) thereafter is performed with less than about 6 milliseconds between any two sequences.

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