

[54] METHOD OF INCREASING SIZE OF
UNDERGROUND NUCLEAR CHIMNEY

[72] Inventor: Daniel Silverman, Tulsa, Okla.
[73] Assignee: Pan American Petroleum Corporation,
Tulsa, Okla.
[22] Filed: Dec. 29, 1969
[21] Appl. No.: 888,577

[52] U.S. Cl. 166/247, 166/308
[51] Int. Cl. E21b 43/26
[58] Field of Search 166/247, 271, 259, 299, 308

[56] References Cited

UNITED STATES PATENTS

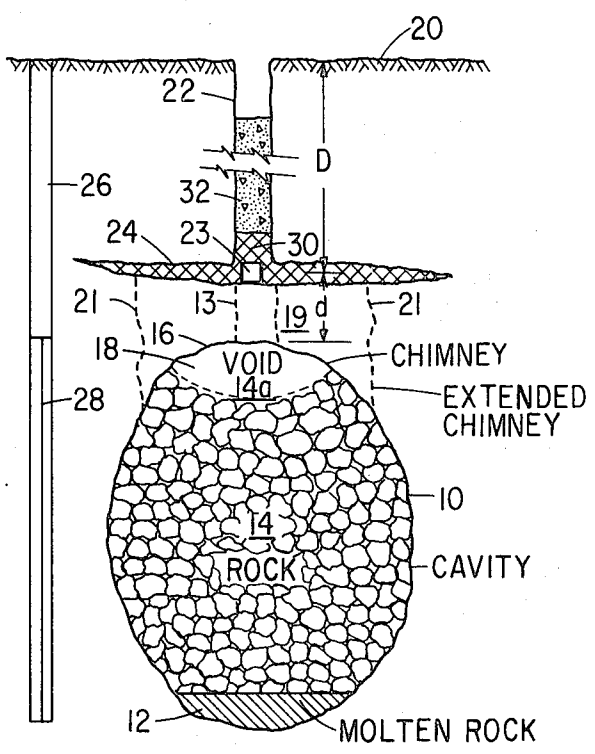
3,303,881	2/1967	Dixon	166/247
3,448,801	6/1969	Closmann et al.	166/247
3,464,490	9/1969	Silverman	166/247 X
3,465,819	9/1969	Dixon	166/247

Primary Examiner—Stephen J. Novosad
Attorney—Paul F. Hawley and John D. Gassett

[57] ABSTRACT

An underground cavity formed deep in the earth by detona-
tion of a nuclear device is extended vertically by drilling a
borehole from the earth's surface to a depth D which is above
the expected top of the cavity chimney by a distance equal to
or greater than d , where d is the thickness of a slab of rock of
the diameter of the chimney that will be self-supporting. A
horizontal propped fracture is created at depth D, and liquid
explosive is placed in the fracture and detonated. The shock
force of the explosion causes the slab of thickness d to be rub-
bleized and driven down into the chimney. This process can be
repeated for successive slabs of thickness d . Alternatively, ver-
tical boreholes can be drilled outside of an adjacent the wall of
the cavity, vertical fractures created with their planes parallel
to the wall of the borehole, the fractures loaded with liquid ex-
plosive and detonated, causing a slab of the wall to be driven
into the chimney and rubbleized.

4 Claims, 5 Drawing Figures



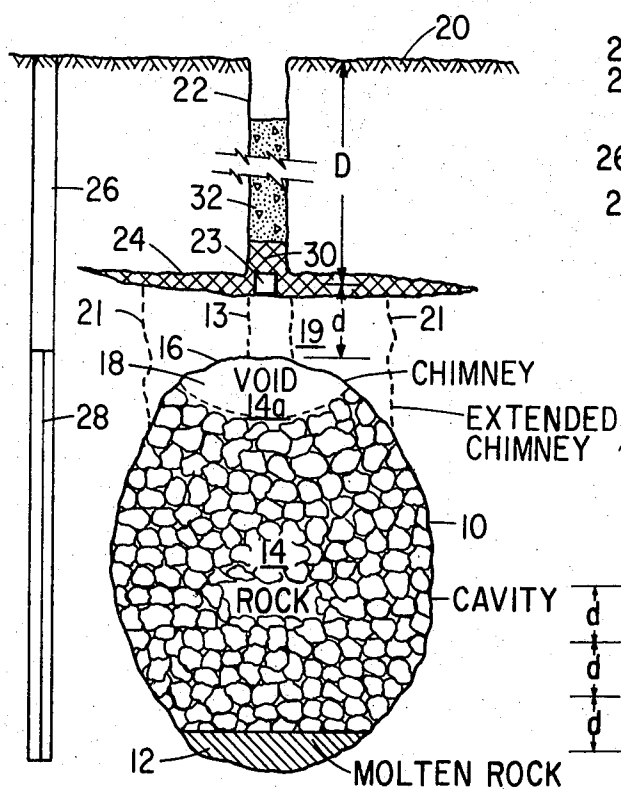


FIG. 1

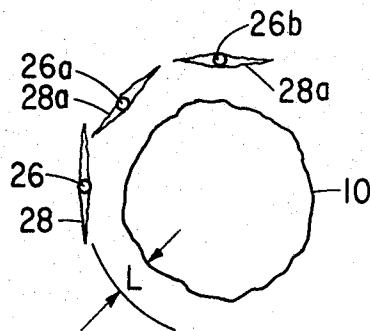


FIG. 2

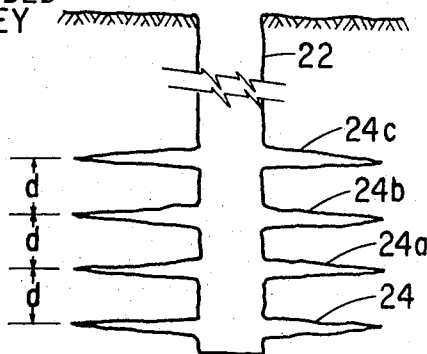


FIG. 3

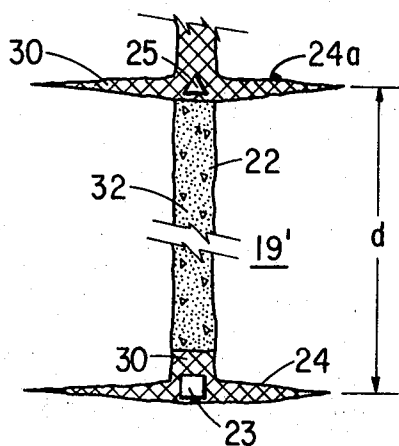


FIG. 4

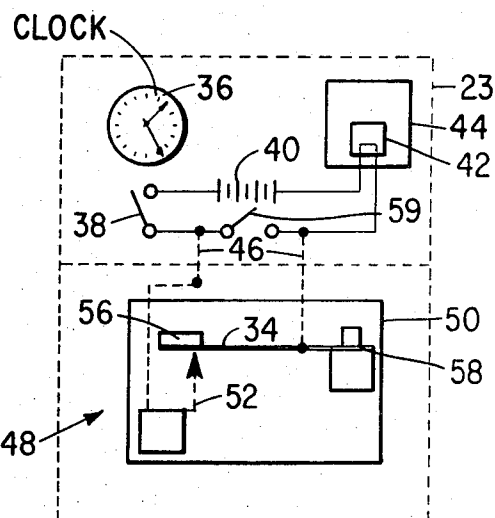


FIG. 5

INVENTOR.
DANIEL SILVERMAN

BY
John D. Gassett
ATTORNEY

METHOD OF INCREASING SIZE OF UNDERGROUND NUCLEAR CHIMNEY

CROSS REFERENCES

This application is related to my U.S. Pat. No. 3,464,490, entitled Formation Nuclear Fracturing Process.

BACKGROUND OF THE INVENTION

This invention relates to the underground detonation of nuclear devices. It relates especially to the use of such underground nuclear explosions in the recovery of minerals and in the recovery of petroleum, in particular. More particularly, this invention relates to methods of extending underground nuclear cavities to larger volumes.

DESCRIPTION OF THE PRIOR ART

When a nuclear device is detonated underground in a confined chamber, a cavity is formed in the formation in a very short period of time. It has further been found that when the cavity is first formed that its walls are lined with melted rock. Most of the melted rock tends to run or drip to the bottom of the cavity. Shortly after the cavity is formed, the roof collapses and broken rock falls into the cavity. The roof collapse continues progressively upward until the top of the resultant column of broken rock supports the overhead. At this point, nearly all of the originally formed cavity is filled with broken rock which extends upwardly. The volume or space in which the broken rock has accumulated is called the "chimney." The diameter of the chimney is approximately the same as that of the cavity and the height may be about two or more times the cavity diameter when measured from a shot point to the top of the chimney. The height of the chimney can be predicted.

The Atomic Energy Commission has conducted several tests underground on nuclear explosions in Nevada. One such test is commonly referred to as the Rainier test, conducted in September 1957. A considerable amount of very useful information has been obtained as a result of such test. For example, much has been learned of the formation of underground cavities and "chimneys" and the relationship of the geometric shape of such chimney to the energy content of the nuclear device and the nature of the rock in which the chimney is formed. It has been found that such chimneys are formed when a nuclear explosion is made in rock which is buried so deeply that it will not cause a crater on the surface of the earth. Further, during the first few microseconds after detonation, the explosion creates a spherical cavity filled with very hot radioactive gas at extreme pressures. This first pressure is very great and is believed to be as much as hundreds of thousands or even millions of atmospheres. The hot gas comes from vaporization of both the explosive itself and water and rock in the immediate vicinity of the explosion. This tremendous pressure forces the cavity to expand until in a very short period, such as a few tenths of a second, it may be as much as 100 feet or more in diameter. The cavity diameter depends largely upon the energy yield of the explosion, the depth at which the nuclear device is detonated, the average depth of the overlying formations and the water content of the host rock. For a further discussion of the size of the cavity, attention is directed to C. R. Boardman, D. D. Rabb and R. D. McArthur, "Characteristic Effects of Contained Nuclear Explosions for Evaluation of Mining Applications"; Lawrence Radiation Laboratory (Livermore) Report UCRL-7350, Rev. I (1963). Thus the size of the cavity can be predicted in advance with a fair degree of accuracy by taking into account the proper factors. It is further seen that by controlling the energy yield of the explosion that within limits the size of the cavity can be controlled.

When a nuclear device is detonated underground, in addition to the high pressure gas discussed above, very severe shock waves are also created. Such shock waves travel in all directions from the point of placement of the nuclear device and would normally be expected to reach the surface of the

earth in a fraction of a second. Directly above the explosion, depending upon the depth and the strength of the nuclear device, the effects of the shock waves are normally quite apparent as a vibrant shaking of the surface of the earth, causing soil, loose rocks, etc., to be disturbed. In fact, these visible effects can give the appearance of breakthrough, but in the case of the Rainier shot, for example, they are merely caused by the shock waves and there was no breakthrough beyond the chimney.

It has been suggested that underground nuclear devices be detonated in or near underground deposits of petroleum to increase recovery.

Many underground formations fail to give up the petroleum due to various reasons such as low permeability in which the petroleum cannot pass through the pore spaces in the reservoir rock and in some cases the petroleum or oil itself is too viscous to flow. In some deposits of petroleum, the oil appears in a form known as oil shale. Although not yet competitive with other forms of obtaining petroleum, oil shale can be mined and processed so as to recover the oil. One such method includes the breaking of the shale into small pieces, mining the broken shale and recovering the oil by retorting at the surface.

It has been suggested that oil be recovered from oil shale by in situ retorting. In one suggested method a nuclear device is detonated, a chimney of broken oil shale is formed in the formation. In such cases, fire is started at the top of the chimney and gas and petroleum collected at the bottom.

An important feature in using underground nuclear explosions in oil shale or in secondary recovery projects is the breaking down of the formation so as to increase its permeability. One might think then that the solution might be to use larger and larger nuclear devices so that more and more of the formation would be broken or fractured. However, this is not the case for several reasons. (1) The cost of the larger nuclear devices might make such procedure prohibitive. (2) A nuclear explosion might not be adequately contained. It is thus seen that it is desired to use as small a nuclear device as possible both to aid in the economics of such recovery and to make it possible to use the energy created in the most efficient manner.

In the prior art a number of patents describe methods of detonating a plurality of spaced nuclear devices, either simultaneously or sequentially, to create a single cavity, the volume of which is greater than the sum of the volumes of the cavities which would have been formed if the devices had been detonated separately. One such patent is U.S. Pat. No. 3,465,818. These systems undoubtedly are workable, but very costly. My U.S. Pat. No. 3,464,490 is directed to accomplishing an increase in volume of a nuclear cavity by forming horizontal fractures in the rock above the chimney to form relatively thin slabs which will not be self-supporting and will fall of their own weight into the chimney, once the nuclear cavity is formed.

SUMMARY OF THE INVENTION

In accordance with one preferred embodiment of the present invention, a placement well is drilled to the formation, such as a shale deposit, which is to be treated. The location and size of the chimney which is wanted in the deposit is selected. A nuclear device is then selected so that the conventionally formed chimney will not extend vertically as far as the one selected. As can be seen, this permits the use of a more economical nuclear device by the use of my invention. In accordance with my invention, before or after the nuclear device is detonated, the formation above the projected or estimated top of the chimney is fractured with one or more horizontal fractures and propped open. These fractures define one or more thick slabs of rock, many times thicker than in the case of U.S. Pat. No. 3,464,490. These thick slabs will be self-supporting and will not fall of their own weight. Sometime after the nuclear device is detonated, liquid explosive is placed in

the lowermost fracture, and detonated, causing the lowermost slab of rock to be driven downward into the chimney as rubble. The next fracture can then be loaded with explosive and detonated and so on. Or a plurality of fractures can be formed, loaded with explosive and detonated substantially simultaneously.

In another embodiment of this invention, one or more boreholes are drilled outside of and adjacent the cylindrical wall of the expected position of the cavity. These are hydraulically fractured with vertical fractures substantially parallel to the wall. These are then loaded with liquid explosive and detonated, blowing the vertical slabs of rock into the cavity as rubble, and extending the cavity outward to the position of the boreholes.

BRIEF DESCRIPTION OF THE DRAWINGS

Various objects and a better understanding of the invention can be had from the following description taken in conjunction with the drawings in which:

FIG. 1 is a schematic diagram illustrating in side elevation view a conventional nuclear cavity in the earth and a horizontal fracture above the chimney and a vertical fracture in a borehole drilled outside the wall of the cavity.

FIG. 2 illustrates in a plan view the relationship of the vertical fractures to the cavity volume.

FIG. 3 illustrates how a plurality of horizontal fractures can be placed above the chimney.

FIG. 4 illustrates how a plurality of explosive loaded fractures can be detonated in succession.

FIG. 5 illustrates the details of a detonating bomb for use in the apparatus of FIG. 4.

DESCRIPTION OF THE PRINCIPAL EMBODIMENTS

Referring now to the drawings and in particular to FIG. 1, I show in schematic fashion an underground nuclear cavity 10. This is presumed to have been formed by detonation of a nuclear device by a process well known in the art, and fully described in my U.S. Pat. No. 3,464,490. Generally, there will be in the bottom a volume of molten rock 12 which has subsequently solidified. Most, if not all, of the remaining volume of the cavity will be filled with rubbleized rock resulting from the fracturing and collapse of the upper part of the cavity called the chimney 16. However, a small volume 14a may still remain free of rock. Dashed lines 13 indicate the well bore drilled for the placement of the nuclear device. However, it is plugged as its only function is for such placement of the nuclear device.

The cavity is shown with its top at some distance ($D+d$) below the earth surface at 20. This distance is quite critical and is a function of the size and energy of the nuclear device. Due to the high gas pressure formed in the cavity during detonation, if there is not enough weight of overburden to contain the pressure, the gas will blow out and create a fissure or vent to the surface, releasing dangerous radioactive materials to the atmosphere. Consequently, based on tests conducted in the earth, it has been learned that for each size of device there is a minimum depth of burial required to contain the explosion. Thus, where the geologic formation of interest is at relatively shallow depth, the nuclear device is limited to a small size and therefore only a relatively small cavity is formed. It turns out that because of the expense of preparing the detonation cavity, placing the device, and because of essential parts of the device which are substantially the same for all sizes, the cost of a relatively low power device is almost as much as that for a much higher power device. So that while we could get increased cavity volume by using multiple small nuclear devices spaced horizontally, the cost would be prohibitive. This invention is directed to the provision of an increased volume of cavity at only a minor increase in cost. The way this is done can be described as follows.

In FIG. 1 is shown above the chimney a borehole 22 to a depth D . By well-known methods, such as by hydraulic frac-

turing, a circular horizontal fracture 24 is made at the base of the borehole 22. This should preferably be at least equal in diameter to that of the chimney. This fracture is propped open by means which are well known in the oil well fracturing art. The fracture is filled with a liquid explosive and detonated. The shock force of the detonation will force the slab of rock 19 downward, fracturing it, and driving the rock rubble into the chimney. This will have extended the volume of the chimney along the circumferential wall 21 up to the plane of the fracture 24.

We have experimented with liquid explosives in fractures in the earth. We find that certain explosives that are now available, such as TAL-1005, made by Talley Industries, Inc., of Mesa, Ariz., can be detonated in crevices as small as one-sixteenth to one-eighteenth inch thick. In one experiment this liquid explosive was placed in a fracture formed in a well drilled into hard limestone, at a depth of 50 feet. High speed movies showed that on detonation the earth surface over the well and fracture rose several feet due to the force of the explosion, and the earth was crisscrossed by deep fissures. It seems reasonable that if the 50-foot limestone slab had been suspended over a void, such as a nuclear cavity, where the explosive force would have been aided by gravity, the slab would have been broken up into rubble.

In carrying out this operation, after the fracture has been formed a time bomb 23 is placed on bottom. These time bombs are commercial articles of commerce. They comprise a clock with a setting mechanism, a booster charge of high explosive, and a means to detonate the charge at the time set. This clock is generally set to detonate at 48 hours after setting. It is placed on bottom and the fracture filled with explosive 30. While I say "filled," there is no way of determining whether the entire void space in the fracture is filled. In practice, a volume of explosive is decided upon such that by experience it will all go into the fracture. After the explosive 30 is in place, cement 32 is placed in the borehole to seal and stem the explosion. Mud, sand, water or other material can be used to fill the borehole to the surface. When the 48 hours are up, the clock detonates the bomb and the bomb detonates the explosive 30, the cement 32, water, etc., serving to close the borehole and contain the explosion.

After the explosive in fracture 24 is detonated and the slab 19 dropped into the chimney, the borehole 22 can be cleaned out to a depth d above the level of 24, and a second fracture 24a (FIG. 4) formed. This fracture 24a can be filled with explosive and detonated, dropping the slab 19' into the chimney and so on. Thus, any amount of upward extension of the chimney can be obtained by sequentially forming fractures and detonating explosives in the fractures, and so on.

I show in FIG. 3 how it is possible to drill one borehole 22 and by means well known in the art form a plurality of fractures at spacings of d . These fractures can be filled with liquid explosive 30 sequentially, starting with fracture 24 (FIG. 4), filling the borehole with cement 32 up to the level of fracture 24a, filling that fracture with explosive, stemming with cement, and so on. These separate layers of explosive should be detonated in sequence, starting with the bottom fracture. This is detonated by a conventional time bomb 23 as described previously. In the second layer would be placed a slightly different time bomb 25. This would be the same as the bomb 23, except that it would have a seismically sensitive switch. This is shown in FIG. 5. Here a clock 36 is arranged to close contacts 38 at a preselected time. This places the terminals of battery 40 onto cap 42 which detonates, and detonates the booster charge 44. This would be the system of the conventional bomb 23 with the switch 59 closed. In the bomb 25 I show by the open switch 59 and dotted lines 46 a seismic switch 48 connected in the lead to the cap. This switch 48 comprises a case 50, lead 52, contact spring 34 clamped at 58 and carrying mass 56. At rest the contact between 52 and 34 is open. When the lower explosive 30 detonates, the shock wave strikes the bottom of the case 50, the mass 56 stands still and the contact 52 moves up to contact 34. Now if the clock 36 is set at an

earlier time than the bomb 23, the switch 38 will be closed, and the closure of contacts 52, 34 will detonate the explosive. By this means the lowermost explosive detonates, then the next one above, and so on. By this procedure the multiple charges are detonated successively after very short time intervals, shorter than say one second. Thus, this procedure differs from that described above where successive charges are detonated after delays of hours or perhaps days. This process simplifies the overall operation since all fractures are created at one time, filled at one time, and detonated at one time. Incidentally, the borehole 22 and all of the fractures can be formed before, or after, the detonation of the nuclear device.

In FIGS. 1 and 2, I show another borehole 26 drilled from the surface to the depth of the cavity, but at a radius from the axis of the cavity greater than that of the cavity wall by a value L. A plurality of these boreholes can be drilled, spaced about the circumference of the cavity. Each of the boreholes 26 is fractured with a vertical fracture 28, the plane of which is parallel to the wall of the borehole.

We have a slab of rock forming the wall of the cavity, of thickness L. Now when the cavity 28 is filled with liquid explosive and detonated, the shock force will blow the slab into the cavity, causing the slab to fracture and rubbleize. By carrying out this process at a number of positions around the periphery of the cavity, the cavity will be enlarged to one having a diameter larger by the value of 2L. If desired, successive pluralities of vertical boreholes can be drilled to progressively enlarge the diameter of the cavity.

Although a large number of boreholes are drilled, they will generally be of shallow depth. Furthermore, they can be rapidly drilled holes, uncased, and therefore much less costly than the normal type of oil field boreholes. Also, these holes can be much smaller in diameter than hole 13 used to place the nuclear device. Further, as in the case of the horizontal fractures, the holes 26 can be drilled and the fractures formed either before or after the detonation of the nuclear device.

While I have disclosed a limited number of specific embodiments of this invention, various modifications can be made thereto by one skilled in the art without departing from the inventive concept, all of which are felt to be part of this invention, the scope of which is to be determined from the scope of the following claims.

I claim:

1. A method of forming and increasing the volume of an underground cavity formed by the detonation underground of a selected nuclear device which comprises:

- a. establishing an underground placement cavity for a nuclear device including a borehole drilled from the surface to the position of said placement cavity,
- b. creating at least one fracture in the rock surrounding the expected position of the cavity, said at least one fracture being a first vertical fracture which is substantially paral-

lel to the cylindrical wall of said cavity and space radially outward from said wall by distance L where L is a thickness of rock slab adapted to be rubbleized by the detonation of the charge of liquid explosive contained within said fracture,

c. placing a nuclear device in said placement cavity, plugging said borehole and detonating said device,

d. placing liquid explosive, whereby the slab of rock between said fracture and said cavity surface will be blown into said cavity and rubbleized.

2. A method as in claim 1 which includes a plurality of such vertical fractures.

3. A method of forming and increasing the volume of an underground cavity formed by the detonation underground of a selected nuclear device, which comprises:

a. establishing an underground placement cavity for a nuclear device including a borehole drilled from the surface to the position of said placement cavity,

b. creating a first horizontal fracture spaced above the expected position of the top of the chimney by a distance greater than d , where d is the minimum thickness of a slab of rock of the formation in which the nuclear cavity is formed that will be self-supporting over the diameter of the chimney,

c. creating a second horizontal fracture spaced above said first horizontal fracture by a distance greater than d ,

d. placing a nuclear device in said placement cavity, plugging said borehole and detonating said device,

e. placing liquid explosive in said first and second fractures and detonating same, the detonation of said explosive in said second fracture occurring at a time less than one second after the detonation of the explosion in said first fracture.

4. A method of forming and increasing the volume of an underground cavity formed by the detonation underground of a selected nuclear device which comprises:

a. establishing an underground placement cavity for a nuclear device including a borehole drilled from the surface to the position of said placement cavity,

b. creating at least one fracture in the rocks surrounding the expected position of the cavity, said at least one fracture spaced from and substantially parallel to the expected position of the outer surface of the cavity,

c. placing a nuclear device in said placement cavity,

d. placing liquid explosive in said at least one fracture,

e. placing a detonator in said liquid explosive, said detonator of a character to be actuated by a shock wave,

f. detonating said nuclear device, the shock waves from such nuclear device actuating the detonator in said liquid explosive whereby said liquid explosive is detonated and blows the slab of rock between such fracture and said cavity surface into such cavity.

* * * * *

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,677,342 Dated July 18, 1972

Inventor(s) Daniel Silverman

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

In the abstract, 5th line from bottom, "an" should be --and--, (page 2, line 11, of Application).

Column 4, line 16, "-eighteenth" should be -- -eighth--, (page 8, line 19, of Application).

Column 6, line 1, "space" should be --spaced--, (Paper No. 3, line 10, of Claim 8).

Column 6, line 8, insert before ", whereby" the phrase --in said at least one fracture and detonating said explosive", (Paper No. 3, line 15, of Claim 8).

Signed and sealed this 23rd day of January 1973.

(SEAL)
Attest;

EDWARD M. FLETCHER, JR.
Attesting Officer

ROBERT GOTTSCHALK
Commissioner of Patents