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**Boardman et al.**

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[54] **EXPLOSIVE FRACTURING METHOD**


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[52] **U.S. Cl.** ..... **166/247,** 299/13

[51] **Int. Cl.** ..... **E21c 41/06,** E21d 43/26

[58] **Field of Search** ..... 166/247, 299; 299/13; 102/22, 23



[56] **References Cited**

UNITED STATES PATENTS

| | | | |
|---|---|---|---|
| 3,470,953 | 10/1969 | Dunlap | 166/247 |
| 3,404,919 | 10/1968 | Dixon | 166/247 X |
| 3,303,881 | 2/1967 | Dixon | 166/247 |
| 3,409,082 | 11/1968 | Bray et al. | 166/247 |

OTHER PUBLICATIONS

Lekas, M. A., et al. Fracturing Oil Shale With Nuclear Explosives For In-Situ Retorting. In Colo. School of Mines Quarterly, July 1965, pp. 7–30.



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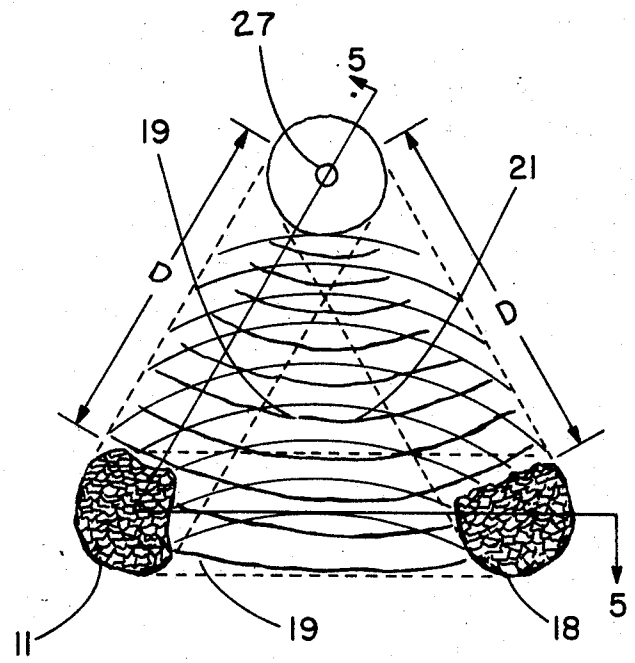
*Attorney*—David Paul Cullen and William R. Laney



[57] **ABSTRACT**

A first explosive, preferably nuclear, is buried at a sufficient depth so that its subsequent detonation is fully contained within the earth. Thereafter a second explosive, also preferably nuclear, is buried a predetermined distance from the situs of the first explosive. After detonation of the first explosive, time is allowed to elapse during which the cavity formed by the first explosive collapses to form a rubblized chimney. Thereafter the second explosive is detonated to create a second chimney parallel to that of the first explosive together with a zone of enhanced permeability between the first and second.


**10 Claims, 5 Drawing Figures**



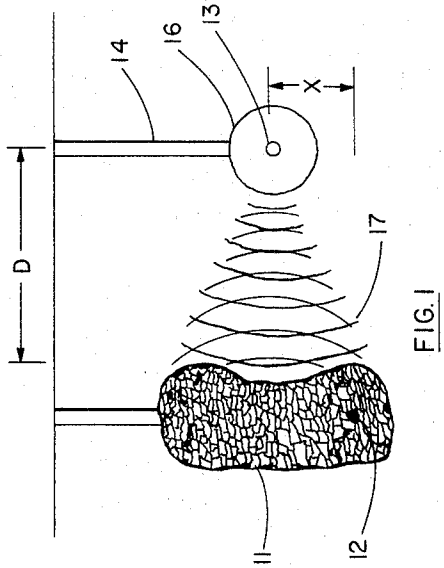



FIG. 1

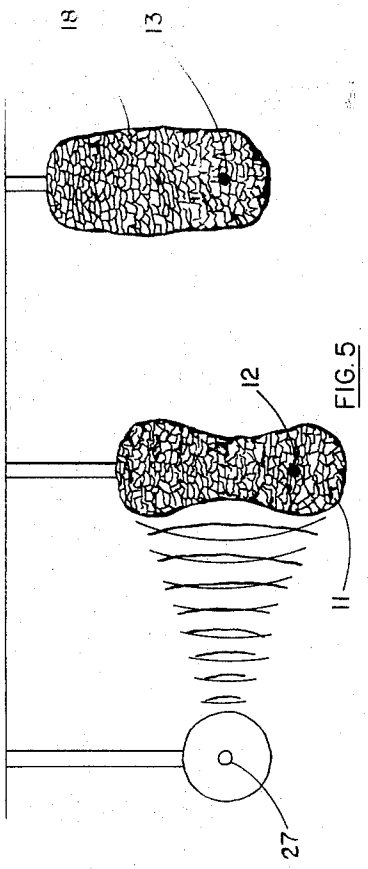



FIG. 5




FIG. 2

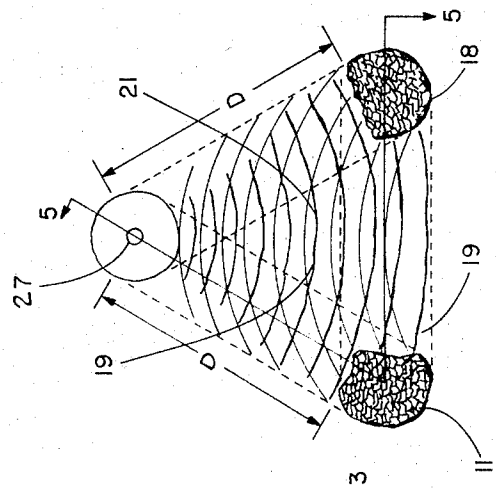



FIG. 3

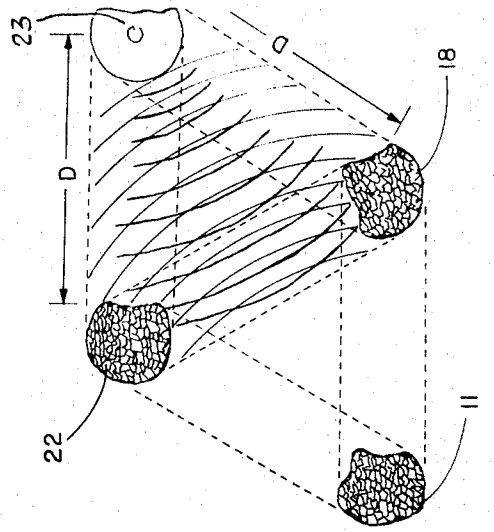



FIG. 4

# EXPLOSIVE FRACTURING METHOD

## BACKGROUND OF THE INVENTION

From the beginning of the industrial revolution until the relatively recent past, man has been fortunate in that the raw materials necessary for the maintenance and growth of his industrial activities have been relatively easy to acquire. Thus, hydrocarbons to power and lubricate the machines of his industry have been available in relatively mobile form from subterranean deposits. These deposits, because of the liquid nature of the hydrocarbons, have been tapped by relatively routine methods, the basic aspects of which were developed in the early days of petroleum exploitation. Similarly, metals such as nickel, copper and the like have, until the present time, occurred in deposits relatively near the surface which could be exploited economically either by drift or strip mining.

As man's technology increases and his demand for raw materials follows apace, the availability of these materials has become a major problem. Since previously adequate sources of raw materials are becoming depleted, it is necessary for man to turn to more remote and complex mineral deposits. In so turning to these new complex sources he finds that new bodies of technology must be developed in order to economically exploit them.

Among the tools which have been suggested for use in exploiting these more remote mineral deposits, nuclear explosives appear to have substantial promise. Because of the tremendous energy released by these devices it is possible to rubblize and fracture large portions of mineral bearing formations, thereby making it possible to treat a substantial quantity of rubblized material by heat or by solution to remove their mineral values.

## TECHNOLOGY BASIC TO THE INVENTION

The basic phenomena which are associated with nuclear explosives have been described many times, and it is not within the scope of this disclosure to again discuss in detail the transient effects of a subterranean nuclear detonation. There are, however, two phenomena which have bearing upon the present invention and which must be understood before the invention can be completely appreciated.

The first of these phenomena involves the formation of a chimney. More particularly, upon the detonation of a nuclear device underground, a cavity containing extremely high pressures is first formed and, for a finite period of time thereafter, it continues to grow and expand, ordinarily in a spherical direction away from the situs of the nuclear explosive. As the pressure within the cavity is reduced due to cooling and contraction of the gases contained therein, the part of the formation immediately above the cavity, which is fractured and broken by the force of the explosion, tends to fall downwardly into the cavity, thereby forming a rubble-filled chimney. The height of the chimney relative to the radius of the cavity varies widely dependent upon a number of factors. Commonly the chimney is from four to six times the radius of the underlying cavity. The material within the chimney is totally rubblized and broken up into pieces of varying size, and the average bulk density of the chimney area is significantly less than the bulk density of the nascent formation.



Collapse of the overlying rock to form a chimney ordinarily takes place within a period of a few minutes to a few hours after the detonation of the nuclear explosive.

There is another phenomenon associated with underground nuclear detonations, which has a bearing on the present invention. More particularly, it has been observed that in some circumstances involving a relatively critical depth of burial of the explosive device, there has formed what has been termed a "retarc." Basically a retarc is said to exist when the formation above the situs of the explosive is fractured and bulked in an upwardly widening conical area to the surface of the earth. At the surface the ground is bulged upwardly. Analysis of the area between the upwardly bulged surface and the working point of the explosive will disclose extremely high permeabilities which are at least as high as the permeability of the rubblized zone in a chimney.

In order to understand the way in which a retarc is formed it is necessary to keep in mind certain dynamic forces which are set in motion by the detonation of a nuclear device underground. More specifically, when such a device is detonated, dilatational waves radiate outwardly therefrom in a spherical direction. When these waves encounter a significant velocity discontinuity in the wave carrying media, such as the surface of the earth, a portion of the wave energy is reflected, some of it being reflected directly back toward the working point, i.e., the situs of the explosive. As the reflected dilatational waves move back toward the working point, they encounter incoming waves, and at certain predetermined points along the vertical section from the earth's surface to the working point, the phase relationships of the incoming and reflected dilatational waves coincide. Where this occurs, if the additive amplitude of the tensile stresses is adequate, the formation will at that point rupture and spalling will occur. The precise location of areas of wave coincidence and resulting spalling will depend upon a number of factors, the most significant of which is the sonic velocity of the surrounding formation. Eventually the additive amplitude of the tensile waves falls below the tensile strength of the formation due to the attenuation of the reflected wave, and no further rupturing or spalling will occur thereafter.

Even, however, when the reflected dilatational wave is significantly attenuated an asymmetric cavity growth has been observed in the area of reflected wave returns. While the reasons for this phenomenon are not fully understood, it is believed that the areas of rarefraction are such as to allow a greater displacement of the formation by the expanding cavity. Due to this phenomenon, an area of extended rupture will occur above the expanding cavity when reflected energy is received during the expansion of the cavity.

A necessary condition for the formation of a retarc is the overlapping of the area of breakage due to spalling with the area of enhanced rupture caused by the interaction of the reflected energy with that of the expanding cavity. In addition, the scaled depth of burial must be such that the material in the ruptured area is displaced vertically due to the force of the explosion.

Because of the requirement for proximity of the two areas of formation rupture coupled with the further requirement that the fractured material not be blown out from a cavity, it is not surprising that the scaled depth of burial at which a retarc will form is usually within the

range of from about 180 to about 250 ft/kt$^{1/3}$. This scaled depth is somewhat lower than the corresponding value for which the upper and lower areas of fracturing will meet without overlapping. Such latter values are calculated from about 250 to about 350.

The variation of results with variation in scaled depth of burial is clearly demonstrated by the following table which summarizes certain critical parameters of a number of underground nuclear detonations.

| Name | Yield (kt) | Medium | Depth | SDB | Results |
|---|---|---|---|---|---|
| Piledriver | 61 | Granite | 1500+ | 380 | Discontinuous areas of enhanced fracturing above chimney separated by about 150 ft. relatively undisturbed formation. |
| Sulky | .087 | Basalt | 90 | 203 | retarc. |
| Neptune | .115 | Tuff | 100 | 206 | retarc. |
| Blanca | 22 | | 840 (calc) | 300 | Fracturing from working point to surface of the earth with about half of the bulking characteristic of a retarc. No surface mound. |
| Hardhat | 4.9 | Granodiorite | 939 | 550 | Discontinuous areas of enhanced fracturing above chimney separated by about 350 ft. of relatively undisturbed formation. |

In considering the foregoing table, it will be noted that it presents a variety of different conditions including different burial depths, different sizes of atomic device and different geological conditions. In spite of these variations, however, the results obtained follow a predictable pattern. More particularly, when the scaled depth of burial was 550 feet, as at Hardhat, the undisturbed area between the upper spall area and the lower area of enhanced fracturing was 350 feet, which, when scaled against the yield, was 205 feet per kiloton$^{1/3}$. When the scaled depth of burial was reduced to 380, as in Piledriver, the gross distance between the upper and lower fracture zones was reduced to 150 feet, with a scaled depth of 38 feet per kiloton$^{1/3}$. which is significantly less than that of the Hardhat experiment. In the Blanca experiment the upper and lower fracture zones intersected and a chimney extended from the working point to the surface of the ground within a relatively short time after detonation of the 22 kiloton device. A retarc was not formed, however. As the scaled depth of burial is reduced as in the Sulky and Neptune shots, retarcs are formed. Moreover, should the scaled depth of burial be reduced to about 160 feet per kiloton$^{1/3}$. or below, material will be blown out of the chimney area to form a Sedan-type crater.

## GENERAL DESCRIPTION OF THE INVENTION

The present invention contemplates a method for creating an area of enhanced permeability between a pre-existing nuclear chimney and a nuclear detonation, which involves spacing the nuclear detonation a scaled distance away from the first formed chimney a distance no greater than the scaled depth of burial at which the spall area and area of enhanced cavity growth from the detonation just meet and do not overlap. Preferably, the scaled distance of separation is equivalent to the scaled depth of burial at which a retarc would be formed by the explosive.

With this type of spacing, dilatational waves radiating from the second explosion will encounter a velocity discontinuity at the surface of the nuclear chimney, whereupon a portion of the wave is reflected back toward the working point of the detonation. As this wave returns, spall zones appear at those places along the return path at which the incoming and reflected waves are coincident and the amplitude of the coincident wave is sufficient to rupture the formation. Because the material within the chimney is relatively compressible as compared with the surrounding formation, these areas of spall can move toward and into a portion of the interior of the chimney to allow bulking of the intermediate formation material. In addition, as the areas of tension immediately following each compressional wave from the reflected dilatational waves appear in the vicinity of the expanding cavity, an area of enhanced fracturing will occur at the side of the cavity next to the chimney from which the waves are reflected. Because of the spacing between the detonation and the pre-existing nuclear chimney, the spalling areas adjacent the chimney and the area of enhanced fracturing adjacent the cavity will intersect with a resulting increase in the permeability of this portion of the formation.

## DESCRIPTION OF THE DRAWINGS

Specific applications of the principles described above may be best understood by reference to the attached drawings, wherein:

FIG. 1 is a side view showing the relationship between a nuclear chimney and the energy from a nuclear detonation;

FIG. 2 is a top plan view showing the nuclear detonation of FIG. 1;

FIG. 3 is a view similar to FIG. 2 wherein a third nuclear detonation has been indicated in its relationship to nuclear chimneys formed by the first two detonations:

FIG. 4 is a top plan view similar to FIG. 3 showing the relationship of a nuclear detonation to three nuclear chimneys; and

FIG. 5 is a cross-sectional view taken along line 5—5 of FIG. 3.

## DETAILED DESCRIPTION OF THE INVENTION

Turning now to the drawings and, in particular, to FIG. 1, there is shown a first chimney 11 formed by the detonation of a nuclear explosive, which was originally located at a working point 12. A second nuclear explosive has been located at a working point 13 through an emplacement hole 14. Working point 13 is situated a distance, $D$, from the adjacent surface of chimney 11. Distance, $D$, which as used herein, is determined by the formula:

$$D = KW^{1/3}$$

Wherein:

$D$ = distance expressed in feet between working point 13 and the adjacent side of chimney 11;

$K$ = a constant having a value up to about 350 and preferably having a value from about 250 to about 3001 ; and

$W$ = explosive energy of the nuclear explosive situated at working point 13 expressed in kiloton equivalents of TNT.

In addition, FIG. 1 represents the conditions within about 60 milliseconds after detonation at which time a cavity 16 is forming around working point 13 and dilatational waves, indicated generally by the number 17, are radiating from the working point in a spherical path. As these waves strike the surface of chimney 11 portions of the formation at the interface will be spalled

into the chimney. Similarly as these waves are reflected from the surface of the chimney backwards towards working point **13**, more spalling will transpire when the incoming waves are coincident with the reflected waves and the resulting tensile stresses are greater than the yield point of the surrounding formation. In addition, the reflected dilatational waves cause enhanced fracturing at the side of the cavity adjacent chimney **11** so that there is formed a generally triangular area of enhanced fracturing having its apex at the cavity and its base at the chimney. Within this area the formation is bulked and its permeability is significantly increased. Moreover, because the dilatational waves interact with the total vertical height of chimney **11** rather than with just a cavity, such as is described by Dunlap in U.S. Pat. No. 3,470953, the volume of material which is bulked and in which permeability is enhanced is significantly increased over prior art methods. In addition, since the present invention contemplates waiting until the pressures surrounding the initial detonation have reduced to the point that cavity collapse occurs, the effect of the second explosion on the formation will be greater than that from the prior art teaching, since portions of the formation spalled toward chimney **11** will not have to move against the extreme pressures of a nascent nuclear cavity.

In FIG. **1** it will be noted that working point **13** is elevated by a distance X above working point **12.** This is a preferred method of developing the bulked area since it allows a more uniform impingement of the dilatational waves from the explosion at working point **13** on the surface of chimney **11** with a consequent more uniform reflection. In general, X will be equal to approximately one-half the distance from the top of chimney **11** to working point **12.** Unfortunately, however, this type of geometrical layout has utility when only a few nuclear chimneys are to be formed. If a substantial area is to be developed using this type of nuclear technology, the distance X will be reduced to zero even though this will, to some extent, reduce the amount of bulked material between successive nuclear explosions.

After a chimney has been formed as a result of the explosion at working point **13,** the area may be further developed by the location of a third device at working point **27** (FIG. **3**) which is located a distance, D, from the adjacent surface of chimney **11** and from the adjacent surface of a chimney **18** which is formed by the explosion at working point **13.** Upon the detonation at working point **27** a bulked area is created in a manner discussed heretofore between working points **17** and chimney **11,** and, likewise, between the working point **27** and chimney **18.** As viewed in FIG. **3,** it will be seen that these bulked areas are merged with the bulked area between chimney **11** and chimney **18** to form a generally triangular area of enhanced permeability as indicated by the dotted lines **19.** In the center of this triangular, bulked area there remains a relatively competent section, indicated by the number **21,** having a roughly triangular cross-sectional configuration. On later treatment, as by solution or by burning of the material in the bulked areas, the portion of the formation shown in area **21** will function to hold the overburden above the bulked areas in the manner of a pillar in room and pillar mining.

The general method of development shown in the FIG. **3** may be repeated in a progressively growing pattern, such as is shown in FIG. **4.** In FIG. **4** the corners of the active triangle are now at chimney **18,** a chimney **22** which is formed by the explosion at working point **27** and a new working point **23.** As in the prior operations, working point **23** is located at a distance, *D*, from adjacent chimneys **22** and **18**; and, as a result, a triangular bulked area similar to the one shown in FIG. **3** is created. This process may be repeated throughout the extent of a formation to leave an area which is substantially fractured, with interspaced pillars to retain the overburden.

## EXAMPLE

In order to further demonstrate the method of practicing the present invention, let it be assumed that it is desired to conduct a shale oil recovery program in the Parachute Creek member of the Green River formation in Rio Blanco County, Colorado. In this area, which is a portion of the Piceance Creek Basin, relatively thick sections of oil shale may be found with minimum overburden of 1,200 feet. An emplacement hole is drilled to the Parachute Creek member and has a total depth of 3,000 feet. A nuclear explosive having a yield of 50 kilotons is then located in the emplacement hole at a depth of 3,000 feet and after stemming, is detonated, whereupon an initial chimney is formed having a diameter of approximately 230 feet and a height of approximately 520 feet. After the formation of the first such chimney, a second emplacement hole is drilled to a depth of 3,000 feet at a distance of 1,000 feet from the first working point. The 1,000 feet distance is determined by the formula

$$D = KW^{1/3}$$

Wherein: *K* has a value of 270; and *W*, as stated earlier, is 50 kilotons.

After emplacement of the explosive in the second emplacement hole and stemming, a second chimney is formed by the detonation of the second explosive. In addition, a bulked area of roughly triangular configuration is formed between the second working point and the first chimney. The rough triangle into which this bulked area is formed has its apex at the second working point and its base along the adjacent side of the first chimney. A total of approximately $4.5\times10^6$ tons of oil shale is included within the bulked area between the two chimneys, while each of the chimneys contains an additional approximately $1.15\times10^6$ tons of rubblized oil shale. After the formation of these rubblized areas subsequent operations are entered into to recover the shale oil from the fractured formation.

It will be appreciated that many different schemes of development of a mineralized area may be employed which utilize the principles of the present invention. Though the methods of triangular development shown in FIGS. **3** and **4** are in most cases preferred, nevertheless, the concept of the present invention will lend itself to any set of circumstances where a nuclear chimney is in existence and it is possible to offset the nuclear chimney with a second nuclear explosion a distance determined by the formula given in the previous parts of the present description. Thus, many modifications may be made without departing from the spirit and scope of the present invention.

What is claimed is:

**1.** A method of forming a horizontally extending subterranean zone having enhanced permeability which comprises:

a. emplacing a first explosive beneath the surface of the earth a sufficient distance so that the detonation from said first explosive will be contained within the earth;

b. emplacing a second explosive beneath the surface of the earth a sufficient distance so that the detonation from said second explosive will be contained within the earth, said second explosive being spaced from the situs of a chimney formed upon detonation of said first explosive a horizontal distance determined by the relationship:

$$D = KW^{1/3}$$

Wherein:

$D$ = distance, expressed in feet, between the situs of a chimney formed upon detonation of the first explosive and the situs of said second explosive;

$K$ = a constant having a value between about 180 and about 350; and

$W$ = the explosive energy of the second explosive expressed in kiloton equivalents of TNT,

said second explosive being emplaced at a situs which is vertically spaced above the horizontal plane extending through the situs at which said first explosive is emplaced prior to its explosion;

c. detonating the first explosive to create a cavity underneath the surface of the earth; and

d. detonating the second explosive at a time after the cavity from the first explosive collapses to form a chimney.

**2.** The method defined in claim **1** wherein said first and second explosives are nuclear.

**3.** The method defined in claim **1** wherein the second explosive is emplaced after the detonation of said first explosive.

**4.** The method defined in claim **2** wherein the second explosive is emplaced after the detonation of said first explosive.

**5.** The method defined in claim **1** wherein the vertical distance at which the situs of emplacement of said second explosive is located above said horizontal plane is a distance which is equal to substantially one-half the distance from the situs of said first explosive to the top of the chimney formed by collapse of the cavity formed by detonation of said first explosive.

**6.** The method of forming a horizontally extended subterranean zone having enhanced permeability which comprises:

a. emplacing a first explosive beneath the surface of the earth a sufficient distance so that the detonation from said first explosive will be contained within the earth;

b. emplacing a second explosive beneath the surface of the earth a sufficient distance so that the detonation from said second explosive will be contained within the earth, said second explosive being spaced from the situs of a chimney formed upon detonation of said first explosive a horizontal distance determined by the relationship:

$$D = KW^{1/3}$$

Wherein:

$D$ = distance, expressed in feet, between the situs of a chimney formed upon detonation of said first explosive and the situs of said second explosive;

$K$ = a constant having a value between about 180 and about 350; and

$W$ = the explosive energy of the second explosive expressed in kiloton equivalents of TNT;

c. detonating the first explosive to create a cavity underneath the surface of the earth;

d. detonating the second explosive at a time after the cavity from the first explosive collapses to form a chimney whereby dilational waves emanating from the detonation of the second explosion are reflected from the discontinuity at the interface between said chimney and the surrounding formation;

e. emplacing a third explosive beneath the surface of the earth a sufficient distance so that the detonation from said third explosive will be contained within the earth and in a triangular array with the situses of emplacement of said first and second explosives, said third explosive being spaced from the situs of the chimney formed upon detonation of said first explosive and from the situs of the chimney formed upon detonation of said second explosive by substantially equal distances, $D$, expressed in feet and determined by the relationship:

$D = KW^{1/3}$

$K$ = a constant having a value between about 180 and about 350; and

$W$ = the explosive energy of the third explosive expressed in kiloton equivalents of TNT;

f. detonating said third explosive at a time after the cavities from said first and second explosives collapse to form chimneys whereby a triangular substantially unfractured pillar is formed in a position centrally located between the situses of detonation of the three explosives and extends vertically for supporting the overburden, and whereby zones of fractured earth of enhanced permeability are formed adjacent the three sides of said triangular pillar and between the three explosion situses.

**7.** The method defined in claim **6** wherein said explosives are nuclear.

**8.** The method defined in claim **6** wherein the third explosive is emplaced after the detonation of the first and of the second explosives.

**9.** The method defined in claim **8** wherein the subterranean zone having enhanced permeability comprises oil shale.

**10.** The method defined in claim **8** wherein the subterranean zone having enhanced permeability comprises metal ore.

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