

[54] **METHOD OF EXPLOSIVELY FRACTURING FROM DRAIN HOLES USING REFLECTIVE FRACTURES**

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[22] Filed: July 2, 1971

[21] Appl. No.: 159,232

[52] U.S. Cl. 166/299, 102/23

[51] Int. Cl. E21b 43/26

[58] Field of Search 102/22, 23; 166/299,
166/259, 271, 258, 247

[56]

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Primary Examiner—Stephen J. Novosad

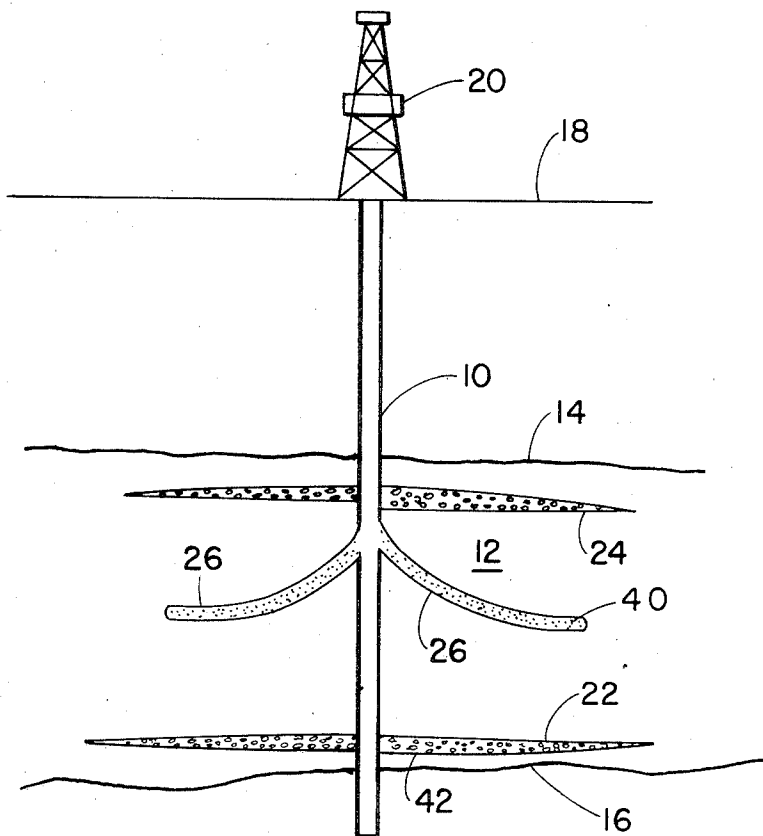
Attorney—George L. Church et al.

[57]

ABSTRACT

A method of increasing fluid conductivity of a formation by drilling horizontal drain holes outwardly from a wellbore and fracturing the formation such that upon detonation of an explosive in the drain hole, the fractures will provide a surface for reflection of the explosive shock waves.

7 Claims, 3 Drawing Figures



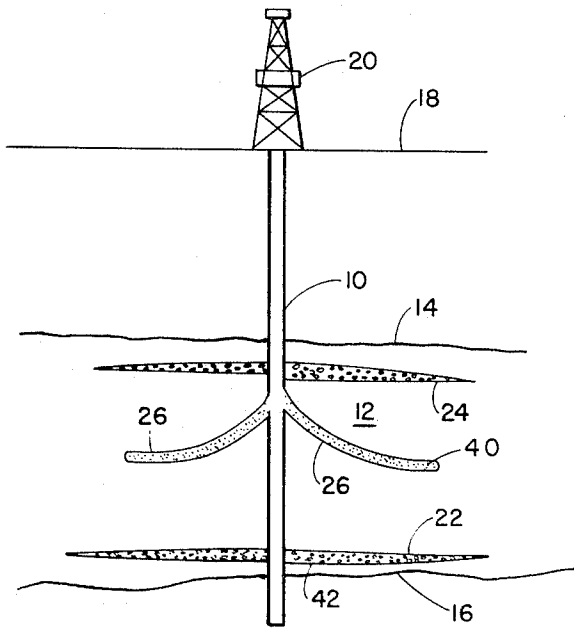


FIG. 1

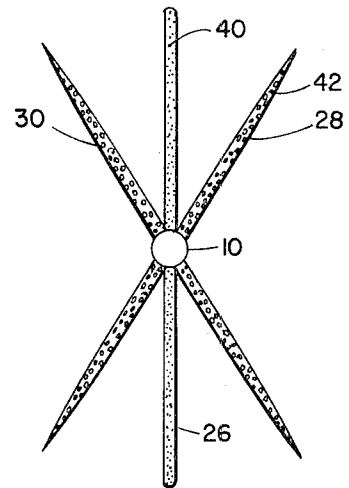


FIG. 2

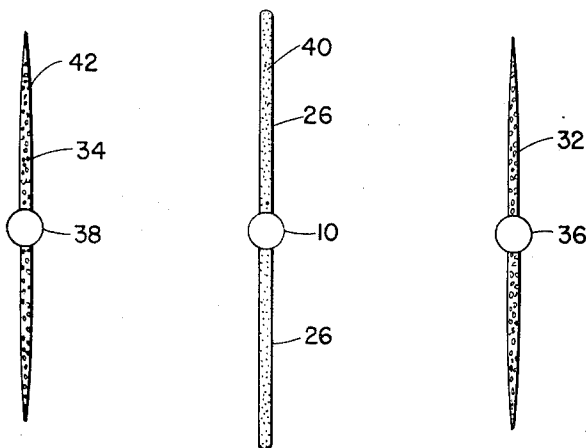


FIG. 3

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METHOD OF EXPLOSIVELY FRACTURING FROM DRAIN HOLES USING REFLECTIVE FRACTURES

BACKGROUND OF THE INVENTION

This invention relates to an improvement in explosively fracturing formations. Extraction of oil or gas as well as the leaching of underground minerals is often complicated by the lack of permeability in the formation. In order to maximize production from such low permeability formation, it is often necessary to fracture the formation and thereby increase permeability. There are two basic methods of creating fractures in a formation. One is to create hydraulic fractures by applying a pressurized fluid against the formation until the formation parts. Another method is to detonate explosives in the formation or wellbore to create a shock wave which fractures the rock matrix of the formation.

Explosive well stimulation has been used for many years. However, explosive stimulation has not been entirely successful. As a result, hydraulic fracturing introduced over 20 years ago has been the standard stimulation mode, due mainly to the high degree of success of this method. Recently, however, new interest in stimulating wells with explosives has been generated by the development of improved explosives and new methods of using them. There are presently two basic methods of explosive fracturing. One is to detonate the explosive in the wellbore, and the other is to detonate the explosive in the formation adjacent to the wellbore. A method of detonating explosives in the formation adjacent the wellbore is to hydraulically fracture the formation, and then load the fracture zone with an explosive material.

When the explosive is confined in the wellbore, the result of detonation is a cylindrical rubble zone in the vicinity of the wellbore surrounded by a system of vertical fractures radiating like wheel spokes from the rubble zone. This result is achieved by the explosive undergoing a very rapid self-propagating decomposition. This decomposition yields more stable products in the form of gases which exert tremendous pressure as they expand at the high temperature generated by the release of heat. This rapid release of energy creates a shock wave.

The rock matrix, adjacent to an explosive charge, will be shattered as the shock wave moves through it. The shock wave consists of two components, compression wave and a shear wave. When the energy level of either of these waves exceeds the strength of the rock under dynamic loading, the rock will fail, thus creating a fracture network. The gases generated in the explosion obtain a pressure on the order of one million pounds per square inch, which pushes against the exposed surfaces of the fractured rock matrix. The expansion of gases will extend the fractures until its energy for doing work is dissipated.

When the explosives are placed in the formation, usually in a fracture created by hydraulic means, a rubble zone will be created in the fracture area upon detonation of the explosive. When an explosive is located in a horizontal fracture and detonated, a high pressure shock wave shatters the adjacent surfaces of the fracture, as the shock wave moves upward and downward from the plane of detonation, it will traverse various strata. As the wave moves through a density discontinuity, part of the wave will be reflected back as a tension wave. The tensile strength of rock is several orders of

magnitude less than the compressive strength, therefore new fractures will be created by the tension wave.

Explosive detonations occurring in vertical fractures yield similar results as those occurring in horizontal fractures. Lateral expansion of the original fracture occurs more readily, however, since the vertical height of the fracture is confined by the stratigraphic boundaries, thus requiring a smaller volumetric increase for fracture extension. Placement of explosives in fractures is not entirely satisfactory due to the limited amount of explosives that can be placed in a fracture created by hydraulic means. The width of fracture controls the net thickness of the explosive layer and thus limits the volume of gas products available for fracture extension. Since the explosive is present as a thin layer, a limited quantity of gas is available per unit surface area of the fracture. It thus can be seen that it will be advantageous to be able to place a larger volume of explosive in the formation. Additionally it is preferable to locate the explosive in the formation rather than in the wellbore so as to prevent wellbore damage and sloughing of the formation adjacent the wellbore.

Since the tensile strength of rock is appreciably less than its compressive strength, it would be preferable to devise a process of explosive fracturing which utilizes a tension wave to a greater degree than is now being practiced. The use of more explosives in the formation together with greater use of tension waves would result in more effective stimulation of the formation.

One method of providing space for more explosives in the formation is by use of drain holes. Drain holes are simply boreholes drilled along a horizontal plane into the formation being produced to provide for more efficient recovery through increased drainage area. The history of drain holes goes back past the turn of the century with early work done in the 1930's. This work was largely unsuccessful due to the economics of the reservoir in which it was used. Revival of drain holes occurred in the 1950's for a brief period and had some success.

Since a 5½ inch hole can be easily drilled by presently known drain hole drilling methods, it can readily be seen that a significantly increased amount of explosives can be located in such a drain hole. Since windows can be cut in the casing and drain holes drilled through the casing window, drain hole drilling is not limited to new wells. Since explosive stimulation is often used in fields that have already been drilled, the casing window feature of drain holes is extremely advantageous.

Because of the limited success of present explosive stimulation techniques, it is an object of the present invention to provide an improved explosive stimulation system.

SUMMARY OF THE INVENTION

With this and other objects in view, the present invention contemplates a system for explosively stimulating earth formations. One or more drain holes are drilled horizontally into the formation from the main vertical wellbore. Hydraulic fractures are created in the formation and are spaced from and parallel to the drain hole. An explosive is loaded into the drain hole and subsequently detonated. Since the shock wave from the detonation will reflect from the fractures which are located parallel to the drain hole, a tension wave results which provides an efficient force to fracture the forma-

tion. In some instances, the formation would be hydraulically fractured before the drain holes are drilled.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a cross sectional elevational view of a sub-surface formation;

FIG. 2 is a cross sectional plan view of a wellbore having drain holes and fractures extending therefrom;

FIG. 3 is a cross sectional plan view of a wellbore having drain holes extending therefrom which are flanked by wellbores which have been fractured.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring first to FIG. 1, there is seen a subterranean formation 12 penetrated by a wellbore 10. The formation 12 has an upper boundary 14 and a lower boundary 16. Hydraulic fracture 24 is created in the formation 12 near the upper boundary 14, and a hydraulic fracture 22 is created near the lower boundary 16. These hydraulic fractures are kept open by a propping agent 42 which is an aggregate material such as sand. With the use of the drilling rig 20 located at the surface 18, drain holes 26 are drilled horizontally into the formation 12. After the drain holes have been drilled an explosive 40 is located in such drain holes.

The creation of the hydraulic fractures 24 and 22 are accomplished by conventional processes. In the normal hydraulic fracturing treatment, fluid is injected down the well casing at rates higher than the rock matrix will accept. This rapid injection provides a build up in wellbore pressure until formation break down occurs. Continued fluid injection will increase the fracture length and width, and in order to keep the fracture open a granular material is injected along with the fracturing fluid to prop open the fracture. The fractures created may be either vertical or horizontal and the fractures shown in FIG. 1 have been illustrated as horizontal fractures. The orientation of the fracture in a horizontal vertical plane is controlled by the magnitude of compressive force due to overburden pressure. Thus, it can be seen that horizontal fractures generally occur in shallow formations and vertical fractures occur in deeper formations.

Drain holes can be drilled by any of several conventional methods which will provide a basically horizontal drain hole which extends from the wellbore 10. One method of drilling such drain holes is to use standard drill pipe which has been dove tail cut to make them flexible, a high angle whipstock and a universal joint. The universal joint is located directly above the drill bit. A rubber liner is used inside the flexible drill collar to conduct drilling mud through the cut pipe. The universal joint is designed to concentrate the force applied to the drill bit, such that the bit will dig to the high side of the hole. The cut drill pipe affords the flexibility to permit the pipe to follow the curved drain hole. Drilling occurs in a conventional manner except that weight on the bit is more critical than in ordinary circumstances. For example, if weight is taken off the drill, the course of the drain hole may be changed toward a substantially vertical direction. After the drain holes have been drilled, they usually are gravel packed or equipped with protective liners.

Another method which has been used for drilling drain holes utilizes a flexible curved drill guide which acts in the manner of a spring and in a free position lies

in a curved plane. This curved drill guide can be used with either a conventional drill bit or with a turbine bit. If it is used with a conventional drill bit, an inner drive pipe having dove tail cuts for flexibility is used as a rotating drill pipe. A high pressure rotary hose is used inside the drive pipe for circulation of mud. Since the curved drill guide extends out into the formation as the drain hole is being drilled, it will be continuously drilled in a curved path, until such time as the drill guide is removed. If horizontal is the desired position of the drain hole, upon reaching horizontal the drill guide is removed and replaced by flexible drill pipe having stabilizers to maintain the drill bit in a horizontal direction. There are other methods for drilling drain holes, however, any workable method can be utilized in the operation of the invention described herein.

In the process of explosively stimulating a formation 12, a previously drilled wellbore 10 can be utilized, or a new wellbore 10 can be drilled. If a new well is being drilled by the use of drilling rig 20, the wellbore should penetrate the entire vertical extent of the formation 12. The wellbore may be cased or uncased when the drain holes are to be drilled. Drain hole drilling equipment is run into the wellbore and the drain hole is drilled by any conventional method, such as those previously described. As shown in FIG. 1, drain holes 26 have been drilled which extend in opposite directions from the wellbore 10. A single drain hole 26 could be utilized or a multiplicity of drain holes could be effectively used. The drain holes 26 may extend out into the formation in excess of 100 feet. There has been some success in the drilling of drain holes up to as much as 150 feet.

After the drain holes 26 have been drilled, liners may be run in to prevent collapse of the hole so as to insure room for placement of an explosive 40. Subsequent to the drain hole drilling and removal of the tools therefor, hydraulic fracturing equipment is moved to the well site. A packer is run into the wellbore so as to isolate the lower portion of the formation 12. Once this zone is isolated, a fracturing fluid is injected down the well casing at a rate which produces pressure large enough to overcome formation stresses.

Once the formation fails, a fracture 22 is initiated, which in this case is in a horizontal plane. Further fluid injection increases the fracture length and width and may be continued until the pump capacities are reached. A granular material, such as sand is included in the injection fluid and displaced into the fracture 22. This granular material 42 is used to prop open the fracture created during the fracturing process. Because this fracture 22 is to be employed as a zone of discontinuity for reflection of shock waves, it is preferable to replace the viscous fracturing fluid with a low density fluid, such as air or water.

Once the lower fracture 22 has been created in the formation 12, the packer is pulled and the upper portion of the formation 12 is isolated by use of a straddle packer. Once the upper portion of the formation 12 has been isolated, the process used for creating the fracture 22 is repeated to create the fracture 24. Upon completion of the creation of upper fracture 24, the straddle packer is removed and the formation 12 is then ready to be loaded with an explosive for fragmentation of the formation. By isolating the drain holes by a straddle packer an explosive is then pumped into the drain holes 26.

Several explosives can be pumped into the drain holes. Desensitized nitroglycerin, nitro paraffins, ammonium nitrate, or TNT in a liquid carrier, could be used in formation fracturing. Since premature explosions have occurred in the use of the newer explosives, it is preferable that the older more stable explosives be used. Desensitized nitroglycerine has been successfully used for many years, and can be recommended for explosive formation stimulation. Once an explosive 40 has been displaced into the drain holes 26, the explosive is detonated by any conventional manner, such as a time bomb.

Upon detonation of the explosive a rapid self propagating, exothermic decomposition occurs. This rapid release of energy creates a shock wave and the rock matrix adjacent to the explosive is shattered as the shock wave moves into the formation. The gases generated in the explosion create tremendous pressure which pushes against the exposed surface of the fractured rock matrix. Gas expansion extends the fractures created by the shock wave. When the shock wave reaches the discontinuous surfaces of fractures 22 and 24, the shock wave is reflected and a tensile wave reflects from the face of the fracture. The change from the high compression of the initial shock wave to the tensile wave causes the formation matrix to fragment when the tensile strength of the rock is exceeded.

The creation of the tensile wave by reflection from the face of the fractures occurs because of a phenomenon known as impedance mis-match. There is a high density contrast between the rock matrix and the fracture zone such that the acoustic impedance of the formation matrix and the fracture zone is quite dissimilar. As the shock wave reaches the face of the fractures 22 and 24, it encounters a sudden change in acoustic impedance. This impedance mis-match causes reflection of the shock wave which causes a tensile wave to travel through the rock matrix. Since the tensile strength of the formation matrix is generally far less than the formation's compressive strength, the tensile wave created by reflection of the shock wave from the face of the fracture provides an efficient fracturing force.

The use of drain holes for placement of explosives is very advantageous due to the amount of explosives that can be placed in the formation. The current method of placing an explosive in the formation, consists of filling a hydraulically created fracture with an explosive. Since the average width of a hydraulic fracture is usually less than 1 inch, there is a severe limitation on the amount of explosive which can be placed therein. Because of the limited fracture width, there is only a small amount of explosive available per square foot of the fracture face. Since the explosive energy released is directly related to the amount of explosive present, any increase in explosive capacity would be advantageous. Because present technology allows the drilling of drain holes in excess of four inches in diameter the amount of explosive that can be placed in the formation is greatly increased by utilizing drain holes. Although FIG. 1 illustrates only two drain holes 26, it is contemplated that additional drain holes could be drilled at various angles from the wellbore 10. Also, many wells with related drain holes and fractures can be used to stimulate the formation.

Referring next to FIG. 2 there is depicted a cross sectional plan view of a wellbore 10 penetrating a formation. Extending from the wellbore 10 into the forma-

tion are fractures 28 and 30 and drain holes 26. The drain hole 26 is shown as being filled with an explosive 40 which may be any explosive capable of being used in wellbore. Fractures 30 contain an aggregate material 42 which may be coarse sand or gravel, or any material which is inexpensive and will operate to prop open the fracture.

The fractures 30 shown extending from wellbore 10 are depicted as vertical fractures, which most often result from hydraulic fracturing in deeper formations. Although in FIG. 1, it was suggested that the drain holes be drilled prior to hydraulic fracturing, that would not be the case in the process depicted by FIG. 2.

When vertical fractures are created in earth formations, the fracture occurs in the plane of least resistance. By various devices, it is possible to create a secondary fracture in a plane that is next most susceptible to breakdown due to hydraulic pressure. Thus, in the process of explosively fracturing a formation which is conducive to creation of hydraulic vertical fractures, it is preferable to create the fractures prior to drilling the drain holes. This procedure is preferable, due to the lack of predictability of determining the direction that both a primary and a secondary fracture would take.

One method of creating the two fracture zones 28 and 30, is to first create the primary fracture along the path of least resistance. Once the primary fracture has been created and propped open by an aggregate contained in the fracturing fluid, it is then squeezed off with cement or by any other means. After the primary fracture has been squeezed off, a second fracture is created along the next least resistant plane. After the two fractures have been created, the orientation of those fractures can be determined by cameras, radioactive tracers, or other means.

Once the fracture orientations have been determined, drain holes should be drilled along a plane which would maximize the effect of an explosive shock wave reflection. As shown in FIG. 2, the primary and secondary fractures 28 and 30 intersect at approximately 60° angles. In such a situation, it would be advantageous to drill the drain hole 26 so that it dissect that 60° angle. It is also anticipated that drain holes could be drilled at right angles to the ones shown in the Drawing.

Once the fractures and drain holes have been created in the formation, the drain holes are filled with an explosive 40 and detonated. The combination of the shock wave and reflection of that shock wave from the face of fractures 28 and 30 to create a tensile wave, will result in extensive fracturing of the rock matrix which should greatly enhance production.

Referring next to FIG. 3, there are seen a multiplicity of wellbores 10, 36 and 38 which are shown in a cross sectional plan view. The wellbores should be drilled such that they are aligned at right angles to the prevalent fracture plane found in the area. From the center wellbore 10, there are drilled drain holes 26, which drain holes are drilled at right angles to the alignment of the wellbores. Shown filling the drain holes 26 is explosive 40, which as previously explained is preferably desensitized nitroglycerin.

From wellbores 38 and 36, shown flanking wellbore 10, there are created hydraulic fractures 32 and 34. By predesign, the fractures 32 and 34 should lie in planes parallel to the drain hole 26 extending from wellbore

10. Aggregate material 42 is located in the fractures 32 and 34 to keep the fractures in an open position.

Once the drain holes 26 and the fractures 32 and 34 have been created, the explosive 40 contained in the drain holes can be detonated. As the shock wave moves from the area of the drain holes toward the fractures 32 and 34, fracturing occurs due to the compressive force placed on the rock matrix. Upon the shock wave reaching the fracture 32 and 34, creation of the tensile wave occurs due to the previously described impedance mismatch. Any number of wells can be alternately hydraulically fractured or drain holed drilled, so that the entire formation can be effectively fractured.

Where vertical fractures are created in the formation and the formation is fractured by the process described in FIG. 3, it is preferable to create the hydraulic fractures prior to the drilling of drain holes. Since the direction of fractures cannot be predicted with certainty, the drain holes should not be drilled until the fractures have been created. Once the fractures are created, the drain holes can be drilled parallel to them, since these holes can be drilled with a fair amount of precision.

If an entire field which has a large number of wells therein is fractured by this method, the predictability of the orientation of the fractures is not critical, if the drain holes are drilled subsequent to the creation of the fractures. In the event that only a few wells are to be drilled into a small reservoir the center well of a three well set up is hydraulically fractured and drain holes are drilled in the outside wells if extensive fracturing is desired. Although the explosive is not as efficiently used, the process allows additional explosives to be placed in the formation for use in the fracturing process.

While particular embodiments of the present invention have been shown and described, it is apparent that changes and modifications may be made without departing from this invention in its broad aspects and therefore the aim in the appended claims is to cover all such changes and modifications as fall within the true spirit and scope of this invention.

What is claimed is:

1. A process for explosively stimulating an earth formation comprising: drilling at least one substantially vertical wellbore into the formation; drilling at least one non-vertical wellbore into the formation; drilling at least one non-vertical drain hole into the formation

from the vertical wellbore; fracturing the formation such that the fractures are spaced from and on opposite sides of the drain hole and wherein the fractures lie in substantially vertical planes with each fracture angled from the drain hole from 10° to 90°; locating an explosive in the drain holes; and detonating the explosive.

2. The process of claim 1 wherein first and second wells are drilled into the formation; the formation is vertically fractured from the second well; and the drain hole is drilled horizontally from the first well parallel to the vertical fracture.

3. The process of claim 2 wherein the first and second wells are drilled on a line at right angles to the fracture planes.

4. The process of claim 1 wherein three aligned wells are drilled; vertical fractures are formed in the outside wells; and the drain hole is drilled substantially horizontally from the center well approximately parallel to the vertical fractures.

5. A process of explosively stimulating an earth formation, comprising: drilling a multiplicity of substantially aligned wells into the formation; fracturing the formation adjacent alternate of the wells, wherein such fractures lie in a vertical plane; drilling horizontal drain holes from the remaining wells where the drain holes are spaced from and substantially parallel to the fractures; positioning an explosive in the drain holes; and triggering the explosive.

6. A process of explosively stimulating an earth formation comprising: drilling at least one well into the formation; fracturing the formation adjacent the well, wherein such fractures lie in a vertical plane, drilling a horizontal drain hole which is spaced from the fractures, wherein both the fractures and drain holes originate from a single well and wherein the drain hole is at substantially right angles to the fractures; positioning an explosive in the drain hole; and triggering the explosive.

7. A process for explosively stimulating an earth formation comprising: drilling at least one well into the formation; fracturing the formation; drilling a horizontal drain hole which is spaced from the fractures; positioning an explosive in the drain hole, said drain hole being at an angle less than 90° from the fracture; and triggering the explosive.

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