FIG. 10

HOLE DRILLED FROM WORK-ROOM

NOTCH FORMED TO INITIATE FRACTURE

WORK-ROOM

22

27

23

FIG. 11

FRAC TURE INITIATED

P R E S S U R E FROM SURFACE

31

33

22

STRADDLE PACKERS

FIG. 11A

INVENTOR.

CARL E. REISTLE, JR.
IN SITU PYROLYSIS OF OIL SHALE FORMATIONS

FIG. 12.

INVENTOR.

CARL E. REISTLE, JR.
IN SITU PYROLYSIS OF OIL SHALE FORMATIONS

FIG. 13.

INVENTOR.

CARL E. REISTLE, JR.
IN SITU PYROLYSIS OF OIL SHALE FORMATIONS

Carl E. Reisler, Jr., Houston, Tex., assignor, by mesne assignments, to Esso Research and Engineering Company, Elizabeth, N.J., a corporation of Delaware

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This invention relates to a method of recovery of organic carbonaceous materials from oil shale formations, and more particularly to a method of in situ pyrolysis or recovery of organic carbonaceous materials from subterranean deposits of oil shale.

In the western part of the United States, particularly in Colorado, Utah, and Wyoming, there are located strata of oil shales covering large areas and ranging up to about 2000 feet in thickness. These formations are composed of kerogen impregnated material that is quite dense and impervious to fluids, and which contains only a very small amount of moisture. The oil shale formations constitute a very large hydrocarbon reservoir. It has been estimated that these formations have a reserve potential of several times as great as that of the prolific Middle East oil fields.

Commercial efforts to exploit oil shale formations have involved techniques for mining the shale and pyrolyzing the mined material in retorts at the earth's surface. Such surface retorting operations have turned out to be extremely expensive, and the resultant liquid hydrocarbons have never been competitive with petroleum products produced by conventional techniques.

A number of techniques have been proposed for retorting the oil shale in place. The technique usually proposed involves sinking vertical shafts into the formations, opening communication between the shafts either by drilling operations or by fracturing operations, and thereafter circulating a thermal fluid to pyrolyze the normally solid organic carbonaceous content of the shales to produce liquid and gaseous hydrocarbons. These hydrocarbons flow from the matrix material, are produced to the surface with the thermal fluid, and are subsequently separated from the thermal fluid at the earth's surface.

In accordance with one aspect of the present invention, a number of substantially horizontal shafts are drilled through an oil shale formation such that at least one of the horizontal shafts fracturing operations are conducted so that the plane of the resulting fracture is vertically disposed so as to open fluid communication at least between said pair of horizontal shafts. Thereafter, there is introduced into the formation along the parted fractured plane a thermal fluid having a temperature sufficient to pyrolyze the oil shale, whereby the sensible heat of the fluid is transferred to the surrounding oil shale formation and pyrolysis and vaporization of the kerogen content of the oil shale occur. The products of pyrolysis and vaporization are entrained in the thermal fluid and are recovered therewith at the earth's surface. After the oil shale is depleted of organic carbonaceous materials, successive fracturing, thermal fluid circulation, and recovery operations are conducted, each successive fracturing operation being at a different horizontal position in the horizontal shaft from which fracturing operations are conducted.

In accordance with another aspect of the invention, the preferred fracture orientation in the oil shale formation is determined. Hydraulically induced fractures in rock formations are normally oriented perpendicular to the direction of least principal stress. In tectonically inactive regions, i.e., in regions where subsurface stresses other than those induced by the weight of the overburden are not present, the least principal stress is substantially horizontal and the induced fractures are substantially vertical. In regions which are tectonically active, the least principal stress may be oriented in any direction between horizontal and vertical, and the orientation of induced fractures will vary accordingly. Preferably, the operation to determine preferred fracture orientation is performed by drilling a plurality of substantially vertical boreholes from the earth's surface into the oil shale formation, exerting hydraulic pressure on the oil shale formation over a substantial portion of the length of each of the boreholes to fracture the oil shale formation, and thereafter determining the orientation in each of the boreholes of the fracture produced therein. Thereafter, a work shaft is drilled into the oil shale formation, and from the work shaft a plurality of substantially horizontal shafts are drilled into the formation in order to penetrate the formation at angles not less than 30° and not more than 90°, of possible relative to the preferred fracture orientation of the oil shale. Thereafter, the formation is fractured from at least one of the horizontal shafts to open communication with at least one other of the horizontal shafts, and thermal fluid is circulated to pyrolyze the oil shale and conduct the products of pyrolysis to the earth's surface. The fracturing, thermal fluid circulation, and recovery operations are repetitively conducted as described above until the formation has been depleted.

Objects and features of the invention not apparent from the above discussion will become evident upon consideration of the following detailed description of the invention taken in connection with the accompanying drawings, wherein:

FIG. 1 is a plan view of a section of an oil shale formation into which have been drilled exploratory wells for determining fracturing planes in the formation;
FIG. 2 is a section of a portion of the earth taken along section 2--2 of FIG. 1;
FIG. 3 is a simplified, schematic diagram with a portion of one of the wells shown in FIGS. 1 and 2 wherein a fracturing operation is being conducted;
FIG. 4 is a sectional view depicting a substantially vertical, oriented fracture, taken along section 4--4 of FIG. 3;
FIG. 5 is a view of the borehole of FIG. 3 wherein a logging operation is being conducted;
FIG. 6 is a sectional view depicting a substantially vertical, oriented fracture, taken along section 6--6 of FIG. 5;
FIG. 7 is a view similar to FIG. 1 illustrating the location of a recovery well in accordance with the invention;
FIG. 8 is an enlarged view of a portion of FIG. 7;
FIG. 9 is a sectional view taken along section 9--9 of FIG. 8 illustrating in schematic form a recovery operation in accordance with the invention;
FIGS. 10, 11, and 11A are diagrammatic views illustrating a fracturing technique in one of the horizontal shafts of FIGS. 8 and 9 in accordance with the invention;
FIG. 12 is a schematic view of the thermal fluid circulation operation on the formations drilled and fractured as illustrated in FIGS. 8 through 11;
FIG. 13 is a plan view and FIGS. 14 and 14A are diagrammatic views of a recovery operation in accordance with the invention illustrating the locations of successive fracturing operations;
FIG. 15 is a view similar to FIGS. 1 and 7 illustrating a zone area of shale oil recovered by following the technique of the invention; and
FIG. 16 is a schematic view in very elemental form of surface recovery equipment that may be used to recover the products of oil shale pyrolysis.

As indicated above, initially it is desirable to determine the preferred fracturing planes or the oil shale formation. The primary reason that this is important is to determine the most effective direction in which to drill the shafts through which thermal fluids are to be circulated into the oil shale. To determine preferred fracturing planes, a plurality of detection wells 3 and 4 are drilled into the oil shale formation 1, as illustrated in FIGS. 3 and 2. The wells are spaced around the oil shale formation at various locations over the areal extent thereof. At least two, and preferably more, detection wells should be drilled into the formation so that a plot of the inclination of the preferred fracturing planes throughout the areal extent of the formation may be obtained. Generally speaking, it will be found that the compass orientation of the preferred fracturing planes will be substantially the same over an extremely large areal extent of the oil shale formation. It is preferable to drill at least one detection well for each area of the each field that is to be serviced by one workroom. The detection wells should penetrate the oil shale formation to a great a depth as possible, and preferably should extend through the interval of hydrocarbon recovery.

After the desired number of detection wells have been drilled, the bedrock are fractured over a substantial portion of the lengths thereof as illustrated in FIGS. 3 and 4. The fracturing fluid may be oil or water, and need not be one of the more exotic fluids such as are used in more conventional oil field operations. The fracturing operation may be conducted by lowering into the well a tubing string 7 having a conventional fracturing packer 13 affixed thereto near the lower end thereof to isolate a section of the borehole 3. In a preferred embodiment of the invention, a radioactive sand is entrained in the last portion of the fracturing fluid so that after the fracture has been opened, the sand will be conducted back into the fracture and will become lodged in the earth formation. The fracturing packer 13 may be set near the upper end of the oil shale zone, or at any depth therein depending on the length of the shale formation to be fractured. If it is desired to fracture only a portion of the shale formation, straddle packers may be used along with a pipe having perforations between the packers, in accordance with usual techniques.

After the formation has been fractured and the radioactive sand 9 has been lodged in the fracture 5 (see FIG. 4), the orientation of the fracture is determined. This may be done by any of a number of techniques. Where radioactive sand is entrained in the fracture fluid and packed into the fracture, a focused radioactivity detector 15 adapted to detect radioactivity over small areas is lowered into the well and is rotated therein. The radioactivity detector may be lowered on a tubing string 11 as illustrated, or may be lowered on a wire line when apparatus for rotating the radioactivity detector is provided, along with drag springs connected thereto for stabilizing the housing in the borehole. Apparatus of this nature has long been used in a service provided by Schlumberger Well Surveying Corporation. Alternatively, photographic apparatus may be lowered into the well and pictures may be taken of the well at various orientations therein to determine the location of the fracture. A photographic survey suitable for such an operation is provided by Laval Underground Surveys, of Fresno, California.

It should be noted that the fracture need not be very large. The distance from each detection well to which each fracture is propagated need be only a few feet. After the orientations of the fractures have been determined, a preferred fracture orientation may be selected for the entire field as illustrated by the lines 3 in FIG. 4. From the plot, the most favorable locations for one or more recovery wells 21 (see FIG. 7) can be determined. The recovery wells comprise a vertical shaft 21a terminating at the lower end thereof in a workroom having a diameter which may be 10 feet or more. The diameter of the shaft 21a should be sufficient to allow workmen to be lowered into the workroom 22 along with equipment that they may need to drill horizontal holes through the formation and to conduct fracturing and other operations to be described below. In order to protect workmen in the workroom 22, the sides of the vertical shaft should be cased and cemented.

The orientations of the horizontal shafts 23 should be such that they penetrate the oil shale formation at angles greater than 30° relative to the orientation of the preferred fracturing planes in the formation as they are drilled through the formation. Most often, the angles of the angle of intersection of a fracture and the horizontal shafts determines the number of wells required to service a given area. Stated in another way, the orientation of the horizontal shafts should be greater than 30° relative to the orientation of the fractures produced in the detection wells 3 as described above. The horizontal shafts may extend away from the well bore for distances up to 2500 feet or more. As illustrated in FIG. 9, the horizontal shafts are drilled into the oil shale formation at each of a number of different levels. Preferably, the levels are spaced between 200 and 1000 feet apart. The shafts may be oriented so that pairs of wells are spaced above or below the other, but such orientation is not absolutely essential as long as the orientation of the shafts is sufficiently close that the shafts are vertically disposed so that fluid communication therebetween can be opened by fracturing, as described below. The drilled horizontal shafts 23 extending laterally from the workroom 22 may be drilled using conventional mechanical bit apparatus, or by using explosive hole-making apparatus for drilling horizontal shafts such as is described in U.S. patent application Serial No. 217,883—R. H. Friedman et al., filed on August 20, 1962. Other techniques may be used, such as those making use of erosive fluids continuously circulated under high pressure.

After the vertical shaft has been located, as shown in FIG. 7, and the circulation shafts have been drilled therefrom, it is necessary to open communication between at least pairs of horizontal shafts. To this end, fractures are initiated nearly at the extremity of at least one of the horizontal shafts. In FIGS. 8 and 9 the fractures on both sides of the workroom 22 are illustrated as having been fractured so that all of the horizontal shafts are interconnected by the fractures 25a and 25b.

In order to facilitate initiation of a fracture at a desired location, a notch may be produced in one of the horizontal shafts 23, making use of apparatus such as that described in the article entitled, "Well-Bore Notching and Hydraulic Fracturing," by H. J. Strain, Journal of Canadian Petroleum Technology, winter, 1962, Calgary. When the notch has been cut in the horizontal shaft 23 (see FIG. 10), a pipe 29 having straddle packers 33 connected thereto is inserted into the shaft 23 so as to isolate the portion of the shaft 23 including the notch 27. This condition is illustrated in FIGS. 11 and 11A. The pipe 29 is connected to a source of hydraulic pressure at the earth's surface 31, and a fracturing fluid, preferably a fluid containing a particulate propping agent, is injected into the space between the packers 33 so as to produce a fracture 25. The fracture is propagated for a time interval of sufficient duration so that the horizontal bore from which the fracture is initiated will be in fluid communication with surrounding horizontal holes drilled in the oil shale formation.

As illustrated in FIGS. 11 and 11A, after the fractures have been initiated to interconnect the desired number of horizontal shafts, certain of the shafts designated in FIG. 12 as 23b and 23d are connected to a source of thermal fluid at the earth's surface through a pipe system.
including manifold 39 controlled by valves 37b and 37d. Holes adjacent the shafts 23b and 23d are connected to manifold pipe 35 through valves 37a, 37c, and 37e, to which is connected surface equipment for separating hydrocarbon products from the thermal fluid. The thermal fluid may be steam, air, or oxygen, to which may be added hydrogen for the purpose of hydrogenating the kerogen to increase the total amount of organic soluble products and to remove most of the sulfur contained in the kerogen, as hydrogen sulfide, and at least a part of the nitrogen, as ammonium compounds. The temperature of the thermal fluid should be at least 700° F. It may be necessary to increase the temperature of the thermal fluid substantially above 700° F., but the temperature should be kept as low as possible inasmuch as undesired degradation of the hydrocarbon products results from high temperatures. In those instances where it is undesirable or impossible to stop the vertical fractures open with particulate propping agent, the pressure of the thermal fluid should be at least 6.8 to .8 p.s.i. for each foot of depth (the probable range of fracture gradients of the oil shale formations) to the maximum depth in the oil shale formation to be hydrolyzed. The fractures may be kept open by the pressure of the thermal fluid.

The thermal fluid will pass down the pipe 38, manifold 39, through the horizontal entry shafts 23b and 23d, into the fracture and out the horizontal exit shafts 23a, 23c, and 23e. In this manner heat will be conducted to the rock. As the temperature of the oil shale reaches the 700°F. to 800°F. level, the solid, high molecular weight kerogen, which constitutes a portion of the shale, decomposes by pyrolysis into lower molecular weight, normally liquid hydrocarbons and gases including hydrogen and carbon dioxide. At 700°F. the normally liquid hydrocarbons exist primarily as gas. Gasification of these gases in situ in the rock produces high pressure in the rock matrix. The resultant pressure gradient from matrix to fracture is sufficient to expel the hydrocarbon and other gases into the fracture. As the mixture of steam and condensable and noncondensable gases moves down the fracture from the steam injection point, its temperature decreases as heat is lost to the surrounding matrix. The steam and condensable hydrocarbons condense and are produced along with the noncondensable gases from the return shafts to the workroom 22, and thence to the surface for separation and further processing for commercial use. The kerogen content of the shale can also be pyrolyzed using heat from combustion of a portion of the hydrocarbon content of the kerogen and the carbon residue which remains bound to the organic portion of the rock following pyrolysis. To apply this recovery technique, wells and fractures will be utilized in the same way as for the steam process. However, instead of steam, air will be injected. Initially, heated air will be injected to raise the fracture faces near the injection well to combustion temperature. Once combustion is started, cool air injection will be continued. The hot gases resulting from combustion and including unburned hydrocarbons will flow down the fracture and serve as the heat transfer medium in the same way as the steam. The combustion zone will move both outward from the fracture faces and down the fracture away from the injection well. Temperature may be controlled if desired by addition of water to the injected air. As the gases cool from heat loss to the rock, the normally liquid hydrocarbons will condense. These hydrocarbons and the noncondensable gases will be produced from the return shafts to the workroom 22 and thence to the surface through pipe 35.

After a period of time the portion of the formation around the horizontal shafts and the fracture therebetween will be depleted of hydrocarbonaceous material to a distance of between 3 and 10 feet therefrom, and it will be found that it is economically undesirable to attempt further production from the formation by circulating thermal fluids through the fracture zone first produced as described above. At this point, the fracture is plugged, as by a conventional cement squeeze, as illustrated in FIG. 14. The thermal fluid is then circulated through the horizontal shafts through which thermal fluids are injected at a distance of about 6 to 10 feet closer to the workroom 22 than the location of the initial notch. The formation is again fractured as previously described by isolating the notch with squeeze packers and exerting hydraulic pressure on the fractured area. Thermal fluid is again circulated until the portion of the formation around the new fracture has been depleted of hydrocarbonaceous materials. This procedure may be repeated as many times as necessary, as indicated in FIGS. 13 and 14, until the zone defined by the horizontal shafts of recovery well 21 has been depleted of hydrocarbonaceous materials, as indicated in FIG. 15.

In FIG. 16 there is illustrated surface equipment which may be used in connection with the oil shale recovery technique described above. The pipe string 53, connected to the manifold pipe 35 and leading from the horizontal shafts through which hydrocarbonaceous materials are produced along with circulating thermal fluid, is connected to a condenser 57, by means of which the thermal fluid and the entrained hydrocarbonaceous materials are cooled so as to condense the hydrocarbonaceous materials. The condensed materials are passed to fractionating towers 51, and, as described hereinbefore, are conducted to a reservoir (not shown) through line 55. The lighter products, which may comprise gas such as methane, along with hydrogen, are passed to a burner 45 through line 59 for the purpose of firing boiler 43. Heated water from condenser 57 is fed into the boiler through line 41, and the superheated steam from the boiler is injected into line 38 and manifold 39 for transmission to the oil shale formation.

Although the embodiments disclosed in the preceding specification are preferred, other modifications will be apparent to those skilled in the art which do not depart from the scope of the broadest aspects of the present invention.

1. An in situ method of recovering shale oil from a subsurface oil shale formation, comprising:
   (a) drilling a substantially vertical shaft into said oil shale formation;
   (b) from said vertical shaft, drilling a plurality of substantially horizontal shafts into the formation;
   (c) from at least one of said horizontal shafts, hydraulically fracturing said formation so that the plane of the resulting fracture is vertically disposed to open fluid communication between said at least one horizontal shaft and at least one adjacent shaft;
   (d) introducing a fluid into the formation along the parted fractured plane, said fluid being at a temperature sufficient to pyrolyze the oil shale, whereby the sensible heat of the fluid is transferred to the surrounding oil shale formation and pyrolysis and vaporization of the kerogen content of the oil shale occur;
   (e) recovering the fluid with products of pyrolysis entrained therein; and
   (f) after the portion of the oil shale around said resulting fracture is depleted of hydrocarbons, successively repeating steps (c), (d), and (e), each fracture initiated as the result of repetition of step (c) being at a different distance from said vertical shaft in said at least one horizontal shaft.

2. An in situ method of recovering shale oil from a subsurface oil shale formation comprising:
   (a) determining the preferential orientation of fractures induced in said oil shale formation at various locations over the areal extent thereof;
   (b) from the earth's surface, drilling a work shaft into said oil shale formation;
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(c) from said work shaft, drilling a plurality of substantially horizontal shafts into the formation oriented to penetrate the formations at angles greater than 30° relative to the preferential orientation of fractures induced in the formation;

(d) with a fracturing fluid carrying a particulate propelling agent, hydraulically fracturing a given plane of said formation by exerting hydraulic pressure on said plane through at least one horizontal shaft, to open up fluid communication between said plurality of horizontal shafts;

(e) introducing a fluid into the formation along the parted fractured plane, said fluid being at a temperature sufficient to pyrolyze the oil shale, whereby the sensible heat of the fluid is transferred to the surrounding oil shale formation and pyrolysis and vaporization of the kerogen content of the oil shale occur; and

(f) recovering the fluid with products of pyrolysis entrained therein.

3. An in situ method of recovering shale oil from a subsurface oil shale formation, comprising:

(a) determining the preferential orientation of fractures induced in said oil shale formation at various locations over the area extent thereof;

(b) from the earth's surface, drilling a work shaft into said oil shale formation;

(c) from said work shaft, drilling a plurality of substantially horizontal shafts into the formation oriented to penetrate the formation at angles greater than 30° relative to the preferential orientation of fractures induced in the formation;

(d) nothing at least one of said horizontal shafts at a given plane of said formation in said oil shale formation;

(e) with a fracturing fluid carrying a particulate propelling agent, hydraulically fracturing said given plane of said formation by exerting hydraulic pressure on said given plane through said at least one horizontal shaft, to open up fluid communication between at least a pair of said horizontal shafts;

(f) introducing a fluid into the formation through the horizontal shafts and the fractures therebetween, said fluid being at a temperature sufficient to pyrolyze the oil shale, whereby the sensible heat of the fluid is transferred to the surrounding oil shale formation and pyrolysis and vaporization of the kerogen content of the oil shale occur and:

(g) recovering the fluid with products of pyrolysis entrained therein.

4. An in situ method of recovering shale oil from a subsurface oil shale formation, comprising:

(a) drilling a plurality of substantially vertical boreholes from the earth's surface through at least a portion of said oil shale formation;

(b) exerting hydraulic pressure on said oil shale formation over a substantial portion of the length of each of said boreholes to fracture said oil shale formation;

(c) at least one depth in each of said boreholes, determining the orientation of the fracture traversing said each borehole;

(d) drilling a work shaft into said oil shale formation;

(e) from said work shaft, drilling a plurality of substantially horizontal shafts into the formation oriented to penetrate the formation at angles greater than 30° relative to the orientation of the fractures produced by step (c) above;

(f) nothing at least one of said horizontal shafts at a given distance from said work shaft;

(g) with a fracturing fluid carrying particulate propelling agent, hydraulically fracturing said oil shale formation along a preferred fracture orientation by exerting hydraulic pressure on the notched zone of said at least one horizontal shaft, to open up fluid communication between at least a pair of horizontal shafts;

(h) introducing a fluid into the formation through said pair of horizontal shafts and the fracture therebetween, said fluid being at a temperature sufficient to pyrolyze the oil shale, whereby the sensible heat of the fluid is transferred to the surrounding oil shale formation and pyrolysis and vaporization of the kerogen content of the oil shale occur; and

(i) recovering the fluid with products of pyrolysis entrained therein.

5. An in situ method of recovering shale oil from a subsurface oil shale formation, comprising:

(a) drilling a plurality of boreholes from the earth's surface through at least a portion of the thickness of said oil shale formation;

(b) exerting hydraulic pressure on said oil shale formation over a substantial portion of the length of said boreholes with a fracturing liquid containing radioactive solid particles to fracture said oil shale formation;

(c) lowering a directionally sensitive radioactivity detector into said boreholes and measuring the orientations of maximum radioactivity in the fractured formation therearound at a plurality of depths thereof to determine the orientation of the fractures therein and the preferred fracture orientation in the oil shale formation;

(d) drilling a work shaft into said oil shale formation;

(e) from said work shaft, drilling a plurality of substantially horizontal shafts into the formation oriented to penetrate the formation at angles greater than 30° relative to the preferred fracture orientation in the formation;

(f) nothing at least one of said horizontal shafts at a given plane in said oil shale formation;

(g) with a fracturing fluid carrying a particulate propelling agent, hydraulically fracturing said given plane through said at least one horizontal shaft, to open up fluid communication between said plurality of horizontal shafts;

(h) introducing a fluid into the formation along the parted fractured plane, said fluid being at a temperature sufficient to pyrolyze the oil shale, whereby the sensible heat of the fluid is transferred to the surrounding oil shale formation and pyrolysis and vaporization of the kerogen content of the oil shale occur and:

(i) recovering the fluid with products of pyrolysis entrained therein.

6. An in situ method of recovering shale oil from a subsurface oil shale formation, comprising:

(a) drilling a plurality of substantially horizontal shafts into the formation, at least pairs of said shafts being vertically disposed so that fluid communication can be opened therebetween by fracturing;

(b) from at least one of said horizontal shafts, fracturing said formation so that the plane of the resulting fracture opens fluid communication at least between vertically disposed pairs of horizontal shafts;

(c) introducing fluid into the formation along the parted fractured plane, said fluid being at a temperature sufficient to pyrolyze the oil shale, whereby the sensible heat of the fluid is transferred to the surrounding oil shale formation and pyrolysis and vaporization of the kerogen content of the oil shale occur;

(d) recovering the fluid with products of pyrolysis entrained therein and:

(e) after the portion of the oil shale around said resulting fracture is depleted of hydrocarbons, successively repeating steps (b), (c), and (d), each fracture initiated as the result of repetition of step
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(b) being at a different horizontal position in said at least one horizontal shaft.

7. An in situ method of recovering shale oil from a subsurface oil shale formation, comprising:
(a) determining the plane of preferred orientation of fractures inducible in said oil shale formation at various locations over the areal extent thereof;
(b) drilling a plurality of substantially horizontal shafts into the formation oriented to penetrate the formation at angles greater than 30° relative to said planes of preferred orientation of fractures in the formation as the horizontal shafts are progressively drilled through the formation, at least pairs of said shafts being vertically disposed so that fluid communication therebetween can be opened by fracturing the formation;

(c) from at least one of said horizontal shafts, fracturing said formation so that the plane of the resulting fracture opens fluid communication at least between vertically disposed pairs of horizontal shafts;
(d) introducing fluid into the formation along the parted fractured plane, said fluid being at a temperature sufficient to pyrolyze the oil shale, whereby the sensible heat of the fluid is transferred to the surrounding oil shale formation and pyrolysis and vaporization of the kerogen content of the oil shale occur;
(e) recovering the fluid with products of pyrolysis entrained therein; and
(f) after the portion of the oil shale around said resulting fracture is depleted of hydrocarbons, successively repeating steps (c), (d), and (e), each fracture initiated as the result of repetition of step (c) being at a different horizontal position in said at least one horizontal shaft.

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CHARLES E. O'CONNELL, Primary Examiner.

S. J. NOVOSAD, Assistant Examiner.