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IN-SITU RECOVERY OF HYDROCARBONS FROM UNDERGROUND FORMATIONS OF OIL SHALE

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FIG. 1

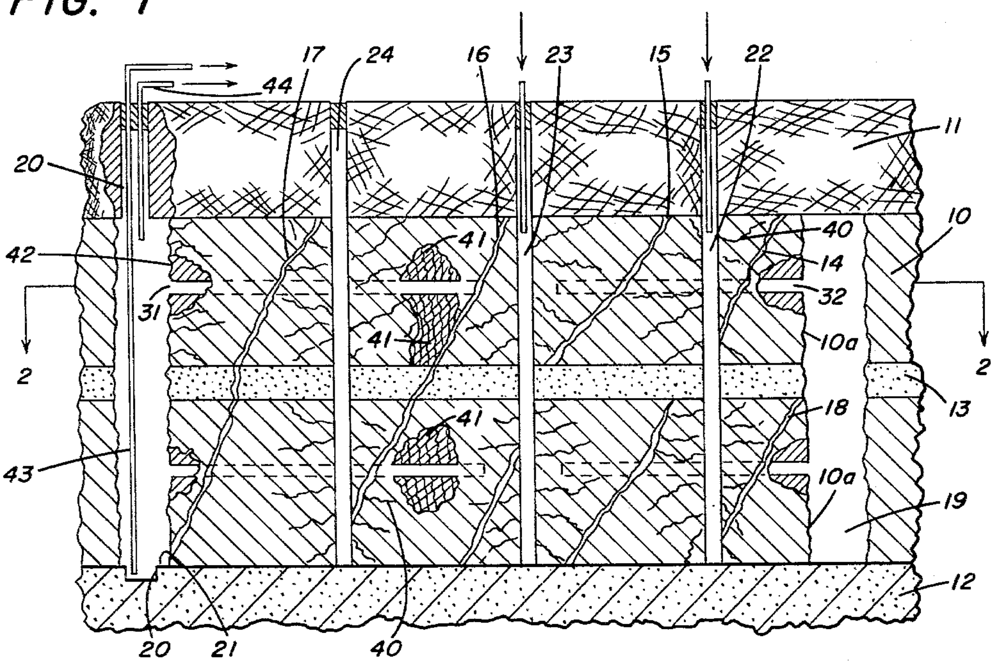
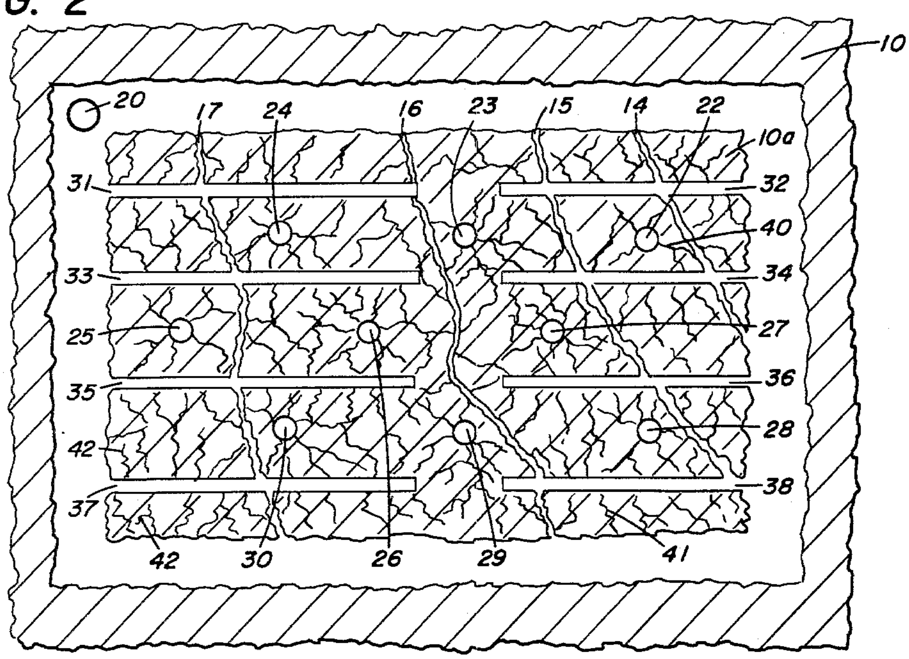


FIG. 2



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IN-SITU RECOVERY OF HYDROCARBONS FROM UNDERGROUND FORMATIONS OF OIL SHALE

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This invention relates to a process for efficient recovery of hydrocarbons from oil shale. More particularly, the present invention is directed toward a process for in-situ retorting and recovery of hydrocarbons from underground formations of oil shale.

Vast deposits of oil shale are located within the United States and are generally disposed beneath the earth's surface in underground formations. The oil shale in such deposits contains hydrocarbons known as kerogen. These hydrocarbons cannot be recovered by conventional petroleum producing methods. Shale containing kerogen must be subjected to retorting or destructive distillation to provide shale oil, which is a hydrocarbon product much like crude petroleum and which may be processed to provide fuels and other useful products. Generally, a ton of oil shale can provide approximately 1 to 50 gallons of shale oil. Thus, these vast deposits of oil shale provide a significant reserve of hydrocarbon materials. Economical production of shale oil from such vast oil shale deposits would be a tremendous contribution to this country's national wealth and provide a great supply of hydrocarbon materials in the event of a national emergency.

Up to the present time no known process for recovering the shale oil from oil shale formations has produced shale oil that, from an economic standpoint, could be reasonably compared to petroleum crude oil.

One such known method for recovering the shale oil is to use conventional mining methods to remove the oil shale from the underground formations where it resides. At the surface, the oil shale is crushed into a size suitable for retorting and is then subjected to retorting. The high costs of such operations in conjunction with the small amounts of shale oil produced prevent utilization of this method on a commercial scale.

Other methods heretofore proposed have been directed toward in-situ restorting of the oil shale to decompose the kerogen therein and educting the hydrocarbon products, i.e., shale oil. Although such processes have avoided some of the expensive conventional mining costs, they are unsatisfactory for one or more reasons from the standpoint of commercial operations. One of these reasons is the low natural permeability of oil shales. Because of this, complicated tunneling and preparation of small isolated units in the oil shale formation have been required to provide sufficient permeability to permit heating the oil shale by passing heated or combustible gases therethrough to drive out the shale oil. Although some processes utilize fracturing of the oil shale, the resultant production of crevices in the oil shale formation has been limited to an extent insufficient to create the required permeability for efficient and relatively complete recovery of the hydrocarbons from the oil shale.

The present invention is directed toward a process for the in-situ retorting and recovery of hydrocarbons from underground formations of oil shale that overcomes the difficulties existing in known processes and which can be used commercially. Further, the process of this invention prepares the oil shale, by extensive and complete fracturing, to the desired degree of permeability to facilitate the ready heating thereof in order to release and drive the hydrocarbons from the oil shale to a common collection area with only a minimum of costly conventional mining operations incurred. In addition, the present process does not depend upon specially disposed formations or highly porous adjacent stratum or fissures for its efficient operation but can use such naturally occurring structures to great advantage in any oil shale formation.

It is therefore an object fo the present invention to provide a process for in-situ retorting and recovery of hydrocarbons from an underground formation of oil shale with greater facility, with maximum recovery of hydrocarbons, and at lower costs than in known processes.

Another object is to provide a process for in-situ retorting and recovery of hydrocarbons from an underground formation of oil shale wherein greater permeability and also more homogeneous permeability is provided to facilitate permeation of such formation with heat sufficient to drive substantial quantities of hydrocarbons from the oil shale for more complete recovery of such hydrocarbons.

Yet another object is to provide a process in accordance with the preceding objects wherein naturally occurring fissures and permeable strata are used to great advantage in recovery of hydrocarbons contained in oil shales.

A further object is to provide a process for in-situ restorting and recovery of hydrocarbons from an underground formation of oil shale that achieves greater efficiency than prior processes by utilizing hydrocarbon-containing materials derived in practicing such process and products produced by such process as sources of heat and eductive agents to assist in removing the hydrocarbons from the shale.

Another further object is to provide a process for in-situ retorting and recovery of hydrocarbons from underground formations of oil shale wherein all openings introduced into said shale formation may be utilized for a dual functioning in such process so that greater efficiency in such process is obtained.

These and other objects will become more apparent when read in conjunction with the following detailed description and the attached drawings wherein:

FIG. 1 shows an illustrative embodiment of the application of the process of the present invention to an underground formation of oil shale with the view taken in vertical section through the earth; and

FIG. 2 is a section taken on line **2—2** of FIG. 1.

The objects are achieved by the process comprising the steps of surrounding a desired portion of the oil shale formation with a horizontally or nearly horizontally disposed tunnel. At least one borehole is provided leading substantially vertically from the earth's surface downwardly into the portion of the shale formation surrounded by the tunnel. The oil shale formation disposed about the vertical borehole is fractured as described hereinafter to a degree providing the desired permeability for efficient retorting of the formation. After fracturing of the oil shale formation, a heat creating gas is injected into the fractured shale formation through the borehole to heat the oil shale formation from adjacent the borehole progressively outwardly to a temperature sufficient to drive the hydrocarbons contained therein away from the borehole and into the tunnel. The recovered hydrocarbons collected in the tunnel are removed to complete the process in its basic concept. Other aspects of the present invention permit additional steps to be incorporated therein to provide certain advantageous results as will be apparent as this description proceeds.

Referring now to the drawings, a detailed description of one illustrative embodiment of the present invention will now be given. In FIG. 1, the oil shale underground formation is designated by numeral **10** and has superimposed an overburden **11** and resides on a more or less impervious substrata **12**.

The oil shale in formation **10** usually occurs in horizontal or nearly horizontal beds as shown and varies in thickness from fractions of a foot to hundreds of feet. The oil shale formation **10** may have interspersed one or more highly permeable strata such as a permeable bed **13** residing more or less parallel to the bedding plane of the oil shale formation. Additionally, natural vertical or nearly vertical fissures **14**, **15**, **16**, **17**, and **18** may be found in oil shale formation **10**.

A portion of the oil shale formation **10** from which recovery of the contained hydrocarbon is desired is surrounded by a horizontally or nearly horizontally disposed tunnel **19**. This portion of the formation **10** will be hereinafter referred to as "surrounded oil shale" and is designated by numeral **10***a*. The tunnel **19** has a vertical dimension generally equal to the thickness of the oil shale to be processed and is connected to the earth's surface by a passageway **20** which serves as a means of access to form the tunnel, an exit through which the tunneling debris is removed, and, later, a place to position apparatus for removing recovered hydrocarbons from the tunnel. Passageway **20** may extend somewhat below the floor **21** of the tunnel to form a central collection area for the hydrocarbons driven from the oil shale. While the surrounded oil shale **10***a* is shown as rectilinear in section, such shape is merely for illustrative purposes and the use of other shapes may be used with equal facility and advantage.

Where the permeability of the overburden **11** or substrata **12** is great enough to provide undesired avenues of escape for the loss of shale oil from the formation surrounded by the tunnel and from the tunnel, layers of the relatively nonporous oil shale may be allowed to remain adjacent the overburden or the substrata. Naturally, such remaining layers of oil shale can be used as roof supporting means to support the overburden **11**. Similarly, the portion of the oil shale selected to be processed for recovery of hydrocarbon may be disposed in a position completely surrounded by the remainder of the oil shale formation **10**.

Generally the size of the tunnel and the portion of the oil shale **10***a* surrounded therewith will depend upon the efficiency of the mode of fracturing utilized and the cost of constructing the tunnel **19**.

A plurality of boreholes are provided into the surrounded oil shale **10***a* and any suitable means such as conventional boring apparatus can be used to provide the boreholes as will be apparent to one skilled in the art. At least one borehole **22** is provided in the oil shale **10***a*. The borehole **22** is substantially vertical with respect to the earth's surface and extends from the surface into the surrounded oil shale **10***a*. The borehole may extend to a depth partially or completely through oil shale **10***a*, or even to pass below it into the substrata **12** depending upon the conditions surrounding the oil shale **10***a*. Preferably a plurality of such boreholes **23** through **30** are provided and are disposed in quantity and disposition in the surrounded oil shale **10***a* whereby substantially complete fracturing of such shale by a fracturing means operated from the boreholes can be obtained. Where naturally occurring vertical fissues are present, one or more of the boreholes may be placed closely adjacent or intersecting such fissures so that upon fracturing crevices **40** are created in the oil shale in communication with the fissures. This is an important advantage in utilizing naturally occurring porous structures to provide greater and more homogeneous permeability throughout the oil shale from which hydrocarbons are to be recovered.

In an oil shale formation having a small vertical dimension, vertical boreholes may be sufficient to obtain extensively complete fracturing of such formation. However, horizontally disposed boreholes may be used where the formation is of a significant vertical dimension such that fracturing from the vertical boreholes is insufficient to provide the desired permeability. They may also be used for other reasons such as utilization of the horizontal permeable bed **13** to assist in eduction of the hydrocarbons driven from the oil shale.

In such instances it may be desirable to provide at least one borehole **31** from tunnel **19** into the oil shale **10***a* that is substantially horizontal. Preferably a plurality of such horizontal boreholes **32** through **38** are provided in the surrounded oil shale **10***a*. Similar boreholes are provided in the lower portion of the surrounded oil shale **10***a* below permeable bed **13** as shown in FIG. 1. The quantity and disposition of such boreholes provided in the oil shale formation are such as to permit fracturing of the formation to a desired degree and extent of homogeneous permeability. Where a naturally occurring, highly permeable stratum, such as permeable bed **13**, is present, it can be used as a ready avenue of eduction for the hydrocarbons driven from the oil shale and for their conveyance to tunnel **19**. In such cases, at least one and preferably a plurality of the horizontal boreholes are placed closely adjacent such naturally permeable stratum. Upon fracturing by fracturing means operated from such boreholes, extensive crevices **41** are created in the oil shale formation which are in communication with the permeable bed **13**. Crevices **41** are shown in a broken section centrally located in FIG. 1.

In some cases it may be desirable to complete tunnel **19** before the drilling of boreholes into the surrounded oil shale **10***a*. However, it is intended to be within the scope of this invention that the particular order of providing boreholes is not contingent upon their being vertical or horizontal nor upon the completion of tunnel **19** but rather will be determined by the conditions present in the oil shale formation.

The positions of the naturally porous structures such as fissures and permeable beds may be determined by observations made in constructing tunnel **19** or by coring operations.

The surrounded oil shale **10***a* is extensively fractured through the use of a fracturing means operated through the boreholes. Any suitable fracturing means can be used such as explosives or hydraulic means. Fracturing from the vertical boreholes will produce crevices **40** which can generally extend radially outwardly as shown in FIGS. 1 and 2. Fracturing from the horizontal boreholes can produce crevices **41** which generally extend radially outwardly as shown in a broken section centrally of FIG. 1 and also in FIG. 2. Preferably crevices **40** and **41** at least in part intersect and also intersect with the naturally porous structures present such as fissues **14** through **18** and permeable bed **13** whereby greater and more homogeneous permeability is obtained in the oil shale. This is an important advantage of the present invention that permits uniform, thorough heating of the oil shale formation and ready eduction of the hydrocarbons therefrom into tunnel **19** for maximum efficient recovery of the hydrocarbons.

Fracturing of the surrounded oil shale **10***a* facing the tunnel **19** may be also achieved as part of the formation of such tunnel, or later, through the use of explosives, and provides crevices **42** extending inwardly into the shale. Other fracturing means can be used if desired.

After fracturing, the oil shale formation must be subjected to heating to decompose kerogen into hydrocarbons. Preferably, heating is to temperatures of the kerogen above 650° F. The fractured oil shale is heated to a temperature sufficient to heat the surrounded oil shale **10***a* to drive the hydrocarbons therefrom and into the tunnel **19** where they are collected for recovery. Because of extensively complete fracturing of the surrounded oil shale **10***a*, ready heating thereof to drive and educt the hydrocarbons is obtained by the relatively free passage of a heat creating gas through the created and natural crevices.

The term "heat creating gas" is used herein to include a gas selected from the group consisting of oxygen containing gases singly or in various proportions and combinations with combustible and noncombustible gases.

The surrounded oil shale 10*a* is heated by injecting a heat creating gas through one or more of the vertical boreholes such as borehole 22 so that the oil shale is heated to the required temperature. The heat creating gas having oxygen containing gases may be preheated initially at the surface by suitable equipment to a temperature sufficient to ignite spontaneously a portion of the hydrocarbon materials in the shale. The combustion of such materials produces heat to decompose the kerogen and to drive the resultant hydrocarbon products from the shale. The heating begins with the shale adjacent the borehole and as the flame front migrates through the formation, the heating moves progressively outwardly from the borehole so as to provide a uniform heat front to drive the hydrocarbon products from the shale and into the tunnel 19. The vertical boreholes not used in the heating of the fractured oil shale formation are sealed or shut in so that only the outlets available for removal of recovered hydrocarbons from tunnel 19 to the earth's surface are one or more passageways 20.

Once the combustion of the oil shale is initiated, the temperature and the velocity of the heat front can be regulated by adjusting the temperature of the heat creating gas being introduced or the volume of such gas or its oxygen content to a degree best suited for maximum recovery of the hydrocarbons from the shale.

In some instances, such as when the hydrocarbon content of the oil shale is relatively low or for other reasons, combustible gases may also be injected into the surrounded oil shale 10*a* and therein ignited. Such combustible gases can provide the only fuel used for heating the shale or to supplement the hydrocarbons used as natural fuel in such shale. The combustible gases may be injected into the shale through one or more of the vertical boreholes, separately or in combination with oxygen containing gases. It may be found desirable in certain aspects of operation to alternately inject the oxygen containing gases and the combustible gases into the surrounded oil shale 10*a*. Noncombustible gases may be admixed with the injected gases to assist in controlling the temperature of the flame front. Alternatively, such gases may be heated to temperatures sufficient to decompose the kerogen in the oil shale and to facilitate the recovery of hydrocarbons therefrom and used separately or in combination with the previously mentioned gases. The selection of any particular mode of injection of the heat creating gas will depend upon the conditions existing in the shale formation. This step of in-situ heating by injecting various gases is well known to those skilled in the art.

Because of the greater and more homogeneous permeability of the fractured oil shale, the heating of the oil shale is readily achieved and, further, the heating is under the most ideal conditions. This is as a result of moving a heating front radially outwardly from one or more central locations toward a peripheral collection zone. There is thus provided maximum recovery of hydrocarbons from the shale.

Further efficiency in heating is obtained by the heat creating gas passing through hot shale from which hydrocarbons have been removed so as to provide preheating of such gas.

The hydrocarbons driven from the surrounded oil shale 10*a* flow through the crevices in the fractured oil shale, the natural fissures and permeable beds present, and also the horizontal boreholes 31 through 38 to collect in tunnel 19 for convenient recovery.

Obviously, an advantage of the present process is that the passageway 20, the boreholes and the tunnel 19 are used for dual purposes, both to prepare the oil shale formation to the desired degree and extent of homogeneous permeability and to facilitate the recovery of the hydrocarbons.

The hydrocarbons driven from the oil shale formation collect in tunnel 19 and are recovered therefrom by suitable conventional liquid and vapor phase collection apparatus. Such apparatus is illustratively shown in FIG. 1 by conduits 43 and 44 extending downwardly through passageway 20 into tunnel 19. Conduit 43 extends into the lowest level of tunnel 19 for removing the liquid phase of the recovered hydrocarbons and conduit 44 spaced therefrom is provided for removing the vapor phase of such recovered hydrocarbons. The conduits may be connected at the earth's surface to conventional recovery and processing apparatus.

The efficiency of this process may be further increased by retorting at least a portion of the rubble and cuttings produced by formation of tunnel 19 on the earth's surface to produce hydrocarbon-containing materials in liquid and gaseous phases. A portion of the gaseous phase can be admixed with the heat creating gas to be injected through the vertical borehole 22 as an additional fuel source to assist in heating the fractured shale formation. The gaseous phase can be also injected into the formation through one or more vertical boreholes other than used for injecting the heat creating gas such as borehole 23 to provide an additional fuel supply in the oil shale for heating same and also to promote more rapid eduction of the released hydrocarbons from the surrounded oil shale 10*a* into the tunnel 19. The gaseous phase of the recovered hydrocarbons can be utilized in a similar manner to the gaseous phase of the retorted rubble and in either instance with or without separation of their noncombustible constituents.

The fracturing of the surrounded oil shale 10*a* by use of the various boreholes may be adjusted to the schedule best suited for expediting the in-situ heating of such shale formation. Thus, the formation disposed about a row of boreholes, vertical or horizontal, along a given line may be fractured and in-situ combustion inaugurated before proceeding with fracturing operations in the other boreholes.

For example, the formation disposed about one or more of the horizontal boreholes, if such are used, may be fractured along with the formation disposed about the row of vertical boreholes 22, 23, and 24. In-situ heating is initiated by injection of a heat creating gas through one or more of the vertical boreholes in such row before fracturing the formation disposed about one or more of the remaining vertical boreholes. Alternatively, the formation disposed about any one, or any group, or all of such vertical boreholes may be fractured before in-situ heating by gas injection is initiated.

The selection and scheduling of the fracturing and injection operations relative to individual boreholes will be determined by the conditions present in specific oil shale formations. It is envisioned to be within the scope of the present invention that different and flexible arrangements both as to selection and scheduling of the fracturing and gas injection operations relative to particular boreholes can be made to secure maximum recovery of shale oil from individual oil shale formations.

Upon completion of the desired recovery of hydrocarbons from the tunnel-surrounded oil shale, tunnel 19 may be extended to enclose a new adjacent portion of the oil shale formation whereupon the novel process of this invention is utilized to recover the hydrocarbons therein.

The use by the present invention of extensive, readily produced boreholes and extensive fracturing reduces drastically the amount of costly conventional mining required for maximum recovery of hydrocarbons from oil shale. In particular, the use of conventional rotary surface equipment can readily and economically produce the vertical boreholes required. Similarly, other known equipment is available for readily providing the horizontal boreholes.

It will be readily appreciated from the foregoing description that herein is fully disclosed a novel process well adapted to obtain maximum recovery of hydrocarbons from underground formations of oil shale and to obtain such hydrocarbons economically and that this process may be extensively used as a means to produce vast quantities of hydrocarbons.

It will be understood that certain features and subcombinations are of utility and may be employed without reference to other features and subcombinations. This is contemplated by and is within the scope of the claims.

As many embodiments as possible may be made of the invention without departing from the scope thereof, it is to be understood that all matter herein set forth or shown in the accompanying drawing is to be interpreted as illustrative and not in a limiting sense.

The invention having been described, what is claimed is:

1. The process of recovering hydrocarbons from underground formations of oil shale comprising the steps of:
(a) surrounding a portion of an oil shale formation with a horizontally disposed tunnel,
(b) providing a plurality of boreholes to said surrounded shale formation wherein at least one said borehole is substantially vertical with respect to the earth's surface and extends from such surface into said surrounded shale formation and at least one said borehole is substantially horizontal and extends from said tunnel into said surrounded shale formation, said boreholes being spaced apart from one another a sufficient distance along their extent in the formation to exclude direct interconnection between any vertical and horizontal boreholes,
(c) fracturing the surrounded shale formation disposed about said substantially vertical and horizontal boreholes,
(d) injecting a heat creating gas through said substantially vertical borehole into said fractured shale formation to heat said shale formation from adjacent said borehole progressively outwardly to a temperature sufficient to drive the hydrocarbons contained in said surrounded shale formation away from said borehole and into said tunnel, and
(e) removing the recovered hydrocarbons from said tunnel.

2. The process of recovering hydrocarbons from underground formations of oil shale comprising the steps of:
(a) surrounding a portion of an oil shale formation with a horizontally disposed tunnel,
(b) providing a plurality of boreholes to said surrounded shale formation wherein at least one said borehole is substantially vertical with respect to the earth's surface and extends from such surface into said surrounded shale formation and at least one said borehole is disposed closely adjacent a naturally occurring permeable structure present within said surrounded shale formation, said boreholes being spaced apart from one another a sufficient distance along their extent in the formation to exclude direct interconnection between any vertical and horizontal boreholes,
(c) fracturing the surrounded shale formation disposed about said boreholes to provide a multitude of crevices at least in part connecting said boreholes with said naturally occurring permeable structure,
(d) injecting a heat creating gas through one substantially vertical borehole into said fractured shale formation to heat same from adjacent said borehole progressively outwardly to a temperature sufficient to drive the hydrocarbons contained in said surrounded shale formation away from said borehole and into said tunnel, and
(e) removing the recovered hydrocarbons from said tunnel.

3. The process of claim 2 wherein said borehole adjacent a naturally occurring permeable structure is substantially vertical with respect to the earth's surface.

4. The process of claim 2 wherein said borehole adjacent a naturally occurring permeable structure is substantially horizontal and extends from said tunnel into said surrounded shale formation.

5. The process of recovering hydrocarbons from underground formations of oil shale comprising the steps of:
(a) surrounding a portion of an oil shale formation with a horizontally disposed tunnel,
(b) providing a plurality of boreholes to said surrounded shale formation wherein at least one said borehole is substantially vertical with respect to the earth's surface and extends from such surface into said shale formation closely adjacent a vertically extending natural fissure and at least one said borehole is substantially horizontal and extends from said tunnel into said surrounded shale formation closely adjacent a natural permeable stratum, said boreholes being spaced apart from one another a sufficient distance along their extent in the formation to exclude direct interconnection between any vertical and horizontal boreholes,
(c) fracturing the surrounded shale formation disposed about said boreholes to provide a multitude of crevies at least in part connecting said boreholes with one another and said fissure and said permeable stratum present in said shale formation,
(d) injecting a heat creating gas through one vertical borehole into said fractured shale formation to heat same from adjacent said borehole progressively outwardly to a temperature sufficient to drive the hydrocarbons contained in said surrounded shale formation away from said borehole and into said tunnel, and
(e) removing the recovered hydrocarbons from said tunnel.

6. The process of recovering hydrocarbons from underground formations of oil shale comprising the steps of:
(a) surrounding a portion of an oil shale formation with a horizontally disposed tunnel,
(b) providing a plurality of substantially vertical boreholes to said shale formation wherein said boreholes extend from the earth's surface into said surrounded shale formation,
(c) fracturing the surrounding shale formation disposed about one of said vertical boreholes, and injecting a heat creating gas through said substantially vertical borehole into said fractured shale formation to heat said shale formation from adjacent said borehole progressively outwardly to a temperature sufficient to drive the hydrocarbons contained in said surrounded shale formation away from said borehole and into said tunnel,
(d) thereafter fracturing the surrounded shale formation disposed around a second of said substantially vertical boreholes and injecting a heat creating gas through said substantially vertical borehole into said fractured shale formation to heat said shale formation from adjacent said second borehole progressively outwardly to a temperature sufficient to drive the hydrocarbons contained in said surrounded shale formation away from said second borehole and into said tunnel, and
(e) removing the recovered hydrocarbons from said tunnel.

7. The process of recovering hydrocarbons from underground formations of oil shale comprising the steps of:
(a) surrounding a portion of an oil shale formation with a horizontally disposed tunnel,
(b) providing at least one borehole to said surrounded shale formation which borehole is substantially vertical with respect to the earth's surface and extends from such surface into said shale formation,
(c) fracturing the surrounded shale formation disposed about said borehole,
(d) injecting a heat creating gas through said borehole into said fractured shale formation to heat said

shale formation from adjacent said borehole progressively outwardly to a temperature sufficient to drive the hydrocarbons contained in said surrounded shale formation away from said borehole and into said tunnel, and

(e) retorting on the earth's surface at least a portion of the rubble and cuttings produced by formation of the tunnel surrounding said shale formation to produce hydrocarbon-containing materials in liquid and gaseous phases,

(f) injecting a portion of said gaseous phase through a vertical borehole other than that used for injecting said heat creating gas into the fractured shale formation to provide additional fuel to heat said shale formation and to promote more rapid eduction of hydrocarbons from the fractured shale formation into the tunnel, and

(g) removing the recovered hydrocarbons from said tunnel.

8. The process of recovering hydrocarbons from underground formations of oil shale comprising the steps of:

(a) surrounding a portion of an oil shale formation with a horizontally disposed tunnel,

(b) providing a plurality of boreholes to said surrounded shale formation wherein at least one said borehole is substantially vertical with respect to the earth's surface and extends from such surface into said surrounded shale formation and at least one said borehole is substantially horizontal and extends from said tunnel into said surrounded shale formation,

(c) fracturing the surrounded shale formation disposed about said substantially vertical and horizontal boreholes,

(d) injecting a heat creating gas through said substantially vertical borehole into said fractured shale formation to heat said shale formation from adjacent said borehole progressively outwardly to a temperature sufficient to drive the hydrocarbons contained in said surrounded shale formation away from said borehole and into said tunnel,

(e) retorting on the earth's surface at least a portion of the rubble and cuttings produced by formation of the tunnel surrounding said shale formation to produce hydrocarbon-containing materials in liquid and gaseous phases,

(f) injecting a portion of said gaseous phase through a vertical borehole other than that used for injecting said heat creating gas into the fractured shale formation to provide additional fuel to heat said shale formation and to promote more rapid eduction of hydrocarbons from the fractured shale formation into the tunnel, and

(g) removing the recovered hydrocarbons from said tunnel.

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