Sept. 13, 1966 J. B. DAHMS ET AL 3,271,962
MINING PROCESS
Filed July 16, 1964 4 Sheets-Sheet 1

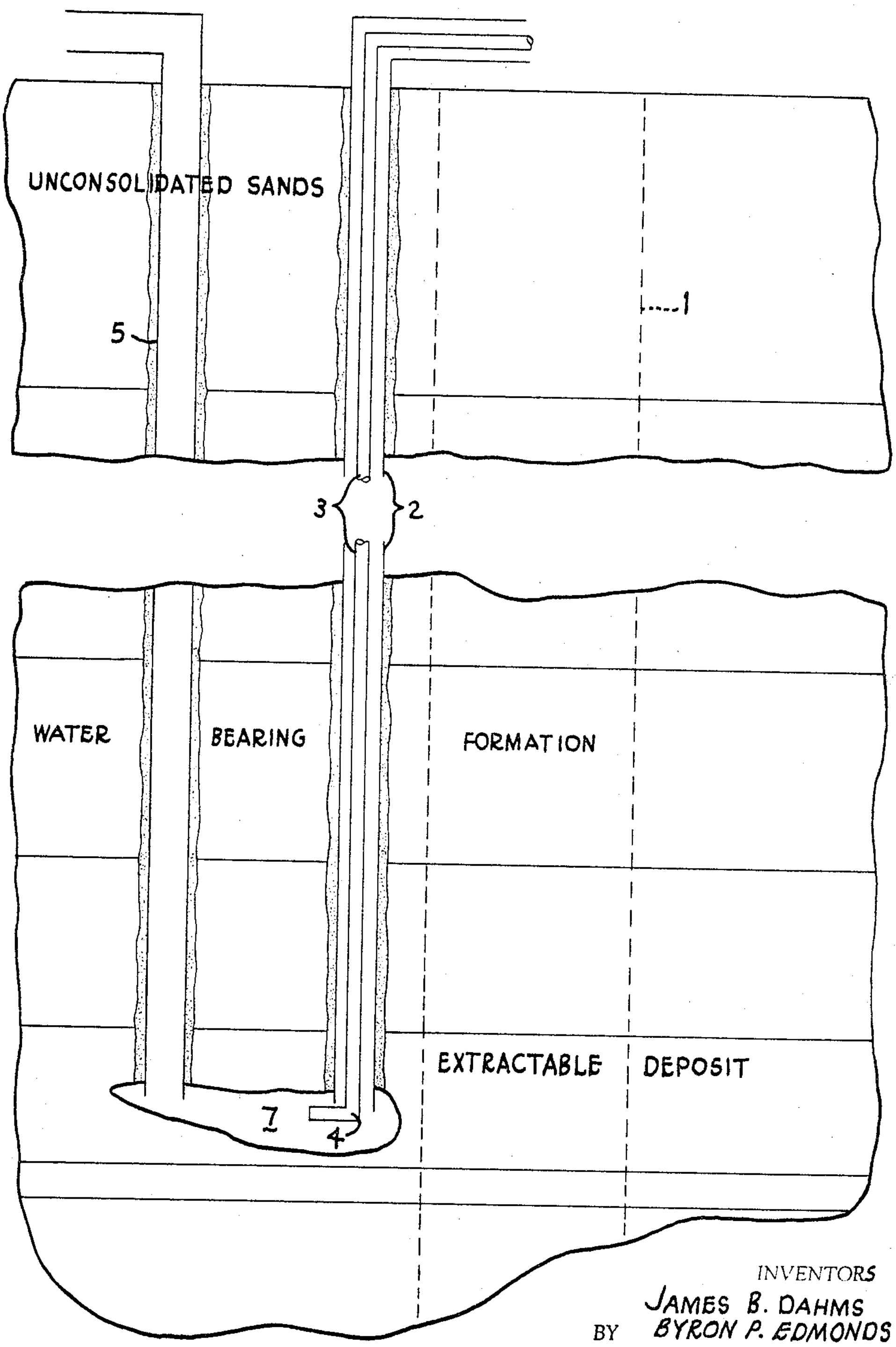

FIG. 1

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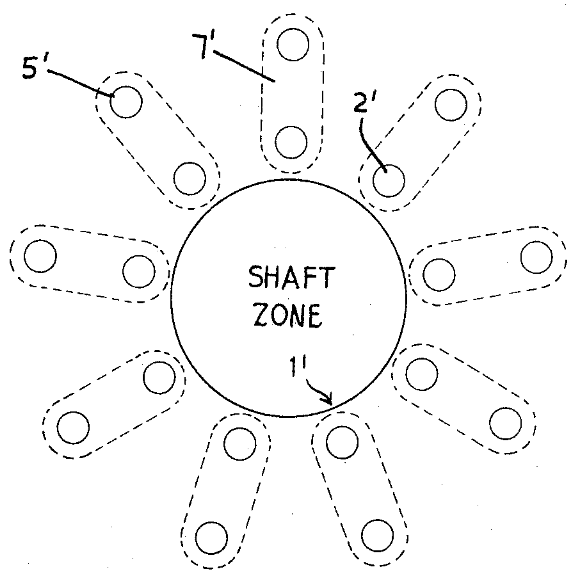

FIG. 2

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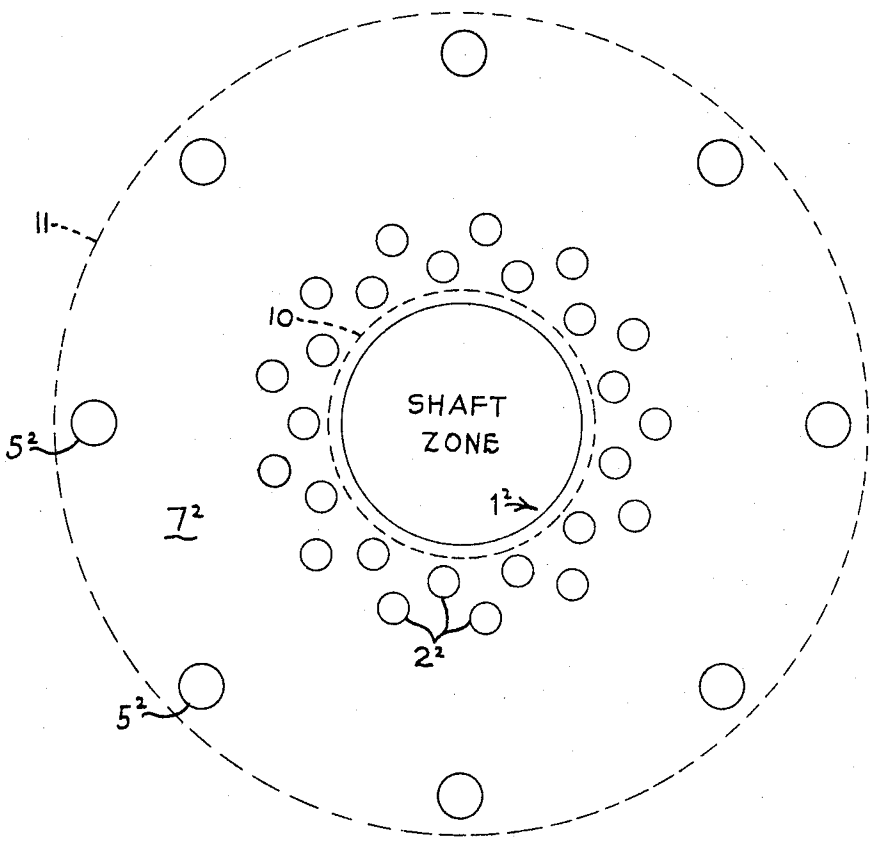
FIG. 3



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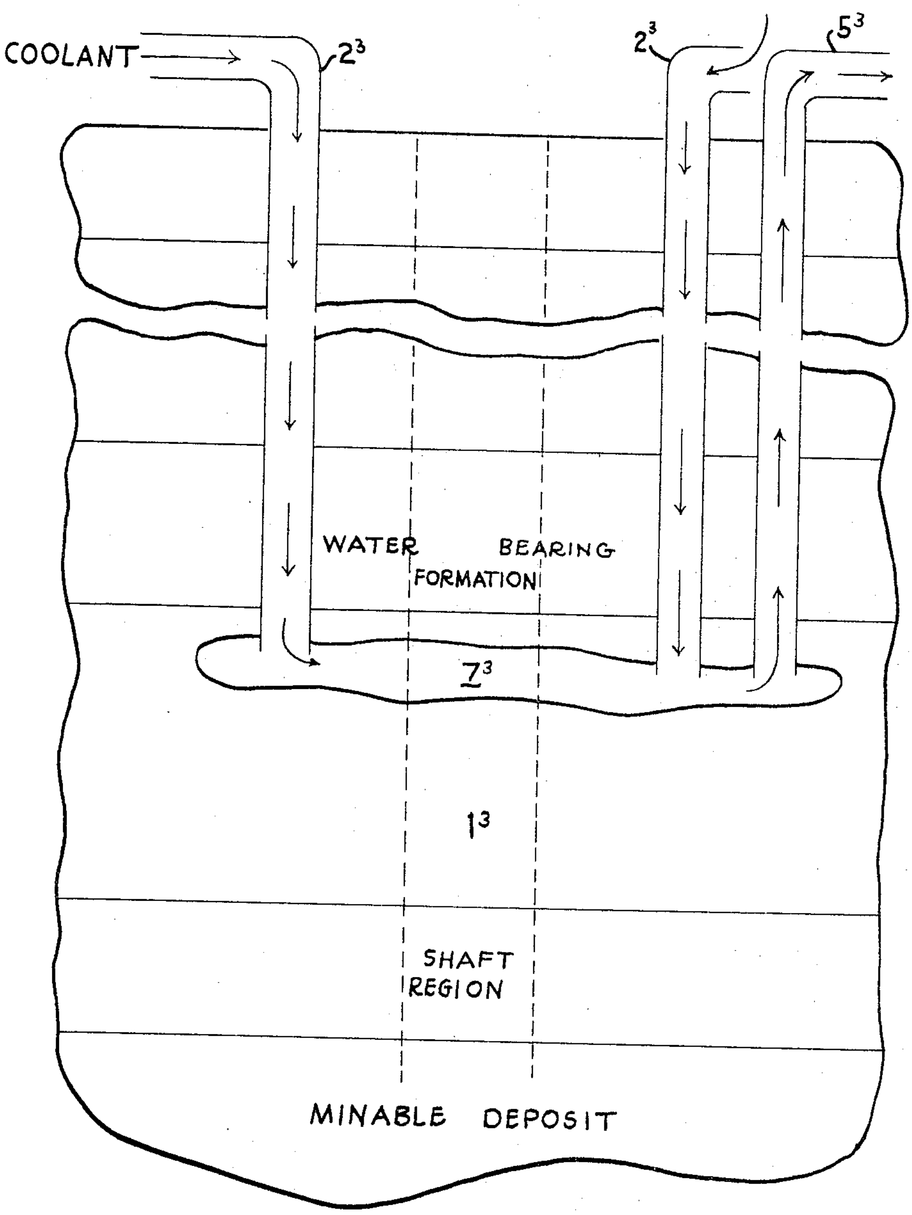

FIG. 4

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United States Patent Office

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Patented Sept. 13, 1966

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3,271,962
MINING PROCESS

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Filed July 16, 1964, Ser. No. 383,123
21 Claims. (Cl. 61—36)

This application is a continuation-in-part of U.S. Serial No. 176,339, filed February 28, 1962, and now abandoned.

This invention relates to freezing water-bearing formations. More particularly, this invention relates to a novel method for freezing water-bearing subterranean formations preparatory to digging therein. This invention has particular application to digging a shaft for the mining of minerals in subterranean formations where the minerals are located beneath the water-bearing formation. Other applications, e.g., in the construction industry, are within contemplation.

On some occasions, the sinking of a shaft to mineral deposits located in a subterranean formation requires drilling and mining through subterranean, water-bearing strata. It is necessary to prevent water flooding the shaft when the shaft penetrates the water-bearing formations. Otherwise, a hazardous condition will result, often requiring the shaft to be closed.

A variety of techniques have been proposed to prevent water flooding a shaft penetrating water-bearing formations. One such technique involves introducing cement or other plastic materials under pressure into the water-bearing sands of the formation. The impregnated sands provide a barrier against water entering the shaft. This technique is expensive, often prohibitively expensive. Another technique involves shielding the perimeter of the shaft. In this technique the shaft is caissoned with iron rings or shields while it is being sunk into and through the water-bearing strata. The iron rings or annular iron shields are cemented in the direction of the shaft. This technique is also very costly.

Another technique which has found some success involves sinking a plurality of cased holes adjacent the shaft vicinity, area, or zone, i.e., the region in which the shaft is to be sunk. These holes are drilled through the water-bearing formation. Centrally positioned in each hole is a tube which is maintained out of contact with the bottom of the hole. To either the interior of the tube or the space exterior of the tube is passed a very cold liquid, typically at a temperature below 0° to —40° C. or more. The liquid is upwardly circulated from the bottom of the hole either to the space outside the pipe or through the pipe. When the liquid is recovered at the surface, it is again refrigerated and recycled to the hole. As a result of this technique, it is possible to freeze water-bearing materials around the shaft thus preventing water flowing into the shaft. An alternative to the concentric pipe arrangement described hereinabove is a continuous tube in the form of a U extending to the bottom of each hole. Several embodiments of this method are disclosed, for example, in U.S. Patents 363,419 and 768,774.

The "freezing" method described hereinabove has been operated with some success though not as efficiently as desired for the purposes at hand. The inefficiency of the prior art method is largely due to loss of heat absorbing capacity of coolant descending to the freeze zones by absorbing heat from the coolant ascending from this zone. The present invention provides a novel "freezing" method whereby significantly increased utilization of the heat absorbing capacity of the liquid coolants is achieved.

According to this invention, separate holes are provided for the coolant descending through the water-bearing formation and the coolant ascending to the earth's surface from beneath the water-bearing formation. A subterranean passage, e.g., a cavity or fissure, is provided through the formation beneath the water-bearing strata. This passage openly communicates with the holes. Thus, coolant is passed down one hole to the subterranean passage. The coolant flows through the passage to a separate hole (withdrawal hole) removed from the first hole (introduction hole). The coolant is withdrawn from the passage through the withdrawal hole to the surface of the earth. In this fashion, no significant amount of heat is absorbed from the ascending coolant stream by the descending coolant stream.

The term "hole" as used herein and in the claims refers to an opening originating at the earth's surface and extending downward through the water-bearing formation. The hole is typically formed by boring, drilling, or impact techniques. The term "hole" includes the casing or equivalent liner which is typically provided in such an opening. Thus, the introduction and withdrawal holes of this invention are typically cased bore holes in which the annular space between the earth and the casing is filled at least partially with grout or cement. The term does not refer to tubing or piping which may be disposed within a "hole" as hereinbefore defined.

In the practice of this invention, an introduction hole is provided through the water-bearing formations adjacent the region it is desired to freeze, e.g., the area, zone, or vicinity where a mining shaft is to be excavated. A plurality of such holes is often provided. Usually these holes are evenly distributed about the periphery of the shaft region, typically close to but out of contact therewith. It is sometimes preferable, however, to provide a hole within the shaft zone.

The introduction hole or holes communicate with one or more subterranean passages, typically cavities, in open contact with one or more separate withdrawal holes. Usually, withdrawal holes are further removed from the periphery of the freeze zone than are introduction holes. Coolant at a temperature below 0° is passed through an introduction hole to a cavity. The coolant is withdrawn from the cavity through a withdrawal hole. Typically, the cavity is out of contact with the shaft region. The cavity may intersect the shaft area, however, either in or beneath the actual space ultimately occupied by the shaft. Often the cavity is in the shape of a donut annularly surrounding the shaft region. This annular cavity typically communicates with a plurality of introduction and withdrawal holes spaced about the shaft. According to a preferred embodiment of the invention, a plurality of introduction holes distributed about the perimeter of the freeze zone each communicates with an individual cavity. The cavities each also communicate with individual withdrawal holes.

The introduction holes of this invention are typically drilled below the water-bearing formation to contact a deposit which contains a substantial amount of extractable minerals. The minerals may be either dispersible or soluble in water and/or mineral acids. Preferably, the deposit contains at least 30 percent by weight of extractable minerals basis the weight of the deposit.

A hole often extends to the mineral deposit which is to be mined (product deposit). It sometimes extends to a stratum, preferably below the product deposit, containing insufficient product minerals for economical mining. Alternatively, the hole may terminate in a limestone or similar type deposit which is extractable with strong mineral acids, such as hydrochloric or sulfuric acid. Such mineral acid extractable deposits are usually above the product deposit. In any event, the introduction holes terminate below the zone or region which contains the objectionable quantities of water.

A coolant having a temperature below 0° to −80° C. or below is fed to the introduction hole. As the coolant is passed down the introduction hole, the water in the water-bearing materials adjacent thereto is frozen. The coolant is collected in the cavity communicating with the bottom of the introduction hole. It is removed from the cavity by way of a withdrawal hole sufficiently removed from the introduction hole that the ascending stream of coolant is out of substantial heat transfer relationship with the descending coolant stream. Often the ascending coolant is sufficiently cold to absorb additional heat from the water-bearing zone as it ascends therethrough.

Typically, the withdrawal hole is spaced further removed from the region of the shaft than is the introduction hole. Sometimes it is desirable to reverse the direction of flow of the coolant. That is, the function of the introduction and withdrawal holes are reversed. In this fashion, the greater cooling capacity of the descending stream is applied more uniformly along the entire freeze zone. It is within contemplation that both introduction holes and withdrawal holes be located in either a single ring or a plurality of concentric rings around the freeze zone.

In the initial cooling of the water-bearing sands, it is usually preferred that the coolant added to the introduction hole have a temperature below −20° C. When the water-bearing formation becomes frozen, it is usually necessary merely to maintain the temperature of the coolant passed to the introduction hole slightly below 0° C. to maintain the water-bearing sands in frozen condition.

As a result of this invention, it is possible to achieve maximum heat transfer between the coolant fed to an introduction hole and the water-bearing materials adjacent the hole. The advantages of this process become readily apparent when one considers the inefficiency in heat transfer of the known freezing method which requires introducing and recovering coolant in a single hole.

In Canada, for example, there are deposits which are exceedingly rich in potassium chloride at a level in excess of 3000 feet below the surface of the ground. Above this deposit are alternate layers of limestone, dolomite and shale wherein is located the main water zone containing thin layers of unconsolidated sand. This main water zone, commencing about 800 feet beneath the surface of the earth, is called the "Blairmore" formation. Above this level is a layer of unconsolidated mud and partly consolidated shale. This upper formation contains very little water. Hence, there is little seepage of water into a shaft sunk in this region. When the shaft contacts the unconsolidated sands containing large quantities of water under relatively high pressure (typically in excess of 200 pounds per square inch) it is fruitless to continue digging unless preventative measures are taken to preclude water's seepage into the shaft.

In the practice of the prior art freezing methods to freeze a formation such as the Blairmore formation, a considerable amount of the potential heat absorbing capacity of the coolant is lost. This loss results from the fact that the region to which the coolant is passed has a temperature of, for example, 30° C. or higher. Thus the coolant absorbs heat from the formation as its passes down the hole. On withdrawal of this heated coolant up the same hole, the ascending stream transfers some of this absorbed heat to the fresh coolant descending down the hole, the fresh coolant and heated coolant being separated only by the walls of the pipes disposed in the hole. To overcome this loss of heat absorbing capacity, it is necessary that the coolant be passed to the hole at a temperature considerably lower than that actually necessary to freeze the water-bearing formation.

In the practice of this invention, the coolant is forwarded from the introduction hole through a cavity located below the water-bearing formation and then withdrawn through a separate withdrawal hole spaced from the introduction hole. In this fashion, the ascending stream of coolant is out of significant heat transfer relationship with the descending stream of coolant. Thus, much more heat is absorbed from the water-bearing formation by a given amount of coolant according to this invention than is absorbed according to the freezing methods of the prior art. When the prior art process requires coolant at −30° C., for example, the coolant employed in the process of this invention under comparable conditions may be fed at −10° C. to achieve the same degree of heat transfer. Thus, a substantial savings in refrigeration of the coolant is effected. In addition, fewer introduction holes than were heretofore found necessary are capable of freezing the area of the shaft to allow digging therein.

The spacing of the introduction and withdrawal holes varies depending upon the size of the zone it is desired to freeze. Typically these holes are separated by distances of 10 to 20 feet although they are often spaced much closer, for example 2 to 6 feet. The holes may be spaced by as little as one foot at the surface of the earth and still effect substantial economic advantages in accordance with this invention.

Preferably a plurality of introduction holes is provided around the freeze region. Usually these holes are provided with casings which are cemented into the hole. In a typical operation, 10 to 40 holes or more may be found necessary. As a general rule, these holes range from 2 to 40 feet outside the outer periphery of the shaft region. Spaced from these holes typically at a distance of 1 to 20 feet from the outermost introduction hole, is provided one or more withdrawal holes. Typically there are employed at least 4 withdrawal holes, evenly spaced around the introduction holes. The withdrawal hole and introduction holes are connected by virtue of openly communicating with a common cavity. All of the withdrawal and introduction holes may communicate with a single cavity or there may be employed a plurality of relatively smaller cavities. By providing several small cavities rather than one larger cavity, the rate of circulation and the temperature of the coolant can be controlled within a more localized area. Although the cavities usually are out of contact with the region of the shaft, it is within contemplation that one or more cavities penetrate this region.

The cavity or cavities can be formed in a mineral product deposit at a point below the water-bearing sand level or at a point below the product, e.g., NaCl, KCl, trona, borax, sylvanite, deposit. If the water-bearing formations are above a limestone deposit which in turn is located above a mineral deposit to be mined, then the hole is desirably drilled into the limestone deposit and a cavity formed therein. If there is no limestone deposit in which a cavity may be effected, then the cavity can be readily formed in the product deposit, typically at its upper level, or at a point vertically below the water-bearing formation. It is also possible to provide a passage in a clay or similar band located below the water-bearing strata.

When the introduction hole terminates in a limestone deposit, the cavity may be formed by introducing a pipe concentrically in the hole and passing a strong acid such as dilute or concentrated HCl or H_2SO_4 thereto. The acid solution extracts the limestone thereby forming a cavity. If it is desired to direct the formation of the cavity away from the shaft region, the portion of the pipe extending into the deposit is provided with a bend so that its open end faces in a direction away from the shaft area. Such a technique is disclosed in United States Patent 2,251,916.

For practicing this technique, the liquid introduced into the hole for extraction purposes is directed away from the shaft, thereby achieving cavity formation in that direction. After the cavity is extended from, for example, 5 to 100 feet, extraction is typically stopped. The withdrawal hole is then, or prior to this time, drilled to contact the cavity. The introduction and withdrawal holes are then openly connected.

Often extraction is effected simultaneously through the withdrawal and introduction holes. When the cavities below each hole connect, the centrally disposed pipes are removed and coolant is circulated as hereinbefore described.

The invention will be better understood with reference to the drawings. FIGURE 1 illustrates development of subterranean passage in an extractable deposit beneath the water-bearing formation. FIGURE 2 illustrates a freezing operation wherein a plurality of independent systems, each of which includes a cavity and communicating bore holes, surrounds the shaft zone. FIGURE 3 shows a specific embodiment wherein a plurality of introduction and withdrawal holes communicate with a single cavity annular to the shaft region. FIGURE 4 illustrates an embodiment wherein the cavity intersects the shaft zone. Of course, the cavity might also be located beneath the deepest point to which the shaft will penetrate.

A specific embodiment in which there is a potassium chloride deposit disposed beneath the water-bearing formation is hereinafter described with reference to FIGURE 1. The mineable deposit typically contains above about 15 percent by weight potassium chloride, basis the total weight potassium chloride and sodium chloride in the deposit. The sodium chloride content is typically in excess of 50 percent by weight of the minerals in the deposit. Above the deposit and disposed therefrom is an extractable (limestone) deposit. Above the limestone deposit is a water-bearing formation wherein water flow rates are typically greater than 500 gallons per minute. Just below the surface of the ground is unconsolidated sand containing water.

Shaft zone **1**, which represents the area in which the shaft is to be provided, has disposed adjacent to it a cement cased bore hole **2** opening into the limestone deposit (designated extractable deposit on the drawing). Centrally disposed in hole **2** is pipe **3**. Pipe **3** is situated in hole **2** so that its outside wall is out of contact with the interior wall of the casing of hole **2**. At the bottom of pipe **3** is elbow pipe **4** pointing in a direction away from the shaft zone **1**.

Concentrated HCl, typically under pressure of about 10 to 500 pounds per square inch, is fed to pipe **3** and elbow pipe **4** to contact the deposit in a direction away from shaft zone **1**. As a result thereof, the limestone is dissolved and removed up through the interior space in hole **2** exterior of pipe **3**. Cavity **7** is thus formed in the limestone deposit. Upon development of cavity **7** to a distance from hole **2** of, for example, about 10 to 100 feet, a cased withdrawal hole **5** is drilled to make open connection with cavity **7**. The acid solution is then removed from the cavity by positive displacement with the coolant or another liquid of higher specific gravity or is flushed out with water. Pipe **3** is removed from cased hole **2**. Coolant is fed to cavity **7** through hole **2** and removed from cavity **7** through hole **5**.

Alternatively, cased withdrawal hole **5** can be drilled simultaneously with hole **2**, and a pipe similar to pipe **3** of hole **2** with an elbow pipe similarly fitted thereon can be provided in hole **5**. In this embodiment, the open end of the elbow pipe **4** would face in the direction of the introduction hole. In this way, extraction can be simultaneously effected through holes **2** and **5** until the cavities formed under each hole connect to form a single passage **7**.

On the other hand, the subterranean passage can be effected by drilling withdrawal hole **5** and extracting solely through this hole. In this fashion, the cavity is expanded until it is close to the shaft zone area. The introduction hole **2** is then provided to effect open communication with the cavity and withdrawal hole **5**.

According to a further embodiment of this specific process, hole **2** may be drilled into a water soluble deposit. Cavity **7** is then formed in this deposit as described hereinabove in connection with the limestone band except that water instead of hydrochloric acid is fed to the deposit. As a result thereof, an aqueous solution is formed and removed via the space in hole **2** exterior the centrally disposed water pipe **3**. When the cavity has developed a proper size, hole **5** is drilled to make open connection with cavity **7**. Then the coolant is introduced to hole **2** at full flow rate to effect freezing of the water-bearing sand zone around shaft zone **1**.

FIGURE 2 shows an embodiment wherein each introduction hole **2'** communicates with a withdrawal hole **5'** by means of separate individual cavities **7'**. Coolant may be introduced in the inner holes **2'** and withdrawn through the outer holes **5'** or the coolant may be introduced into outer holes **5'** and withdrawn through the inner holes **2'**. Usually, all of the holes closer to the shaft are utilized as introduction holes. In this fashion, the relatively cooler descending coolant stream is in contact with the area closest to the shaft.

FIGURE 3 illustrates an alternative embodiment wherein a plurality of introduction and withdrawal holes are disposed around the shaft area. As shown in FIGURE 3, shaft area $\mathbf{1^2}$ is centrally disposed. Surrounding the shaft area are a plurality of introduction holes $\mathbf{2^2}$, each of which opens into an annular cavity $\mathbf{7^2}$ depicted by the area within hatch marks **10** and **11**. Inserted through the formation are withdrawal holes $\mathbf{5^2}$ which open into the cavity. In FIGURE 3, there are shown 26 introduction holes and 8 withdrawal holes. Fewer or more holes may be effectively employed.

The number of introduction holes employed is determined, for example, by the depth of the water-bearing formation, its temperature and the rate of flow of the water therein. For example, referring to FIGURE 3, a shaft zone $\mathbf{1^2}$ has a diameter of 24 feet and extends vertically through a 250 foot thick water-bearing formation located 1800 feet below ground surface of the formation. The shaft zone is surrounded by 18 cased introduction holes $\mathbf{2^2}$. The water-bearing formation contains 2.5 gallons of water per cubic foot of sand at a temperature of 30° C. The water is at a pressure of 850 pounds per square inch. The 18 introduction holes are equally spaced and annularly surround the shaft zone at distances of 10 to 20 feet out from the perimeter of the shaft area (zone or region). The cased introduction holes have a 4-inch internal diameter and a 4½ inch external diameter. These holes communicate with a common annular cavity $\mathbf{7^2}$. Each of the introduction holes is fed a liquid coolant such as unsaturated calcium chloride brine solution at a temperature of −10° C. or lower. Once the water-bearing sands are frozen, the temperature of the coolant may range from −5 to −20° C. Coolant is removed from the cavity through withdrawal holes $\mathbf{5^2}$ as illustrated in FIGURE 3. The coolant introduced into the hole may be, for example, liquid ammonia or an aqueous potassium chloride or sodium chloride brine. In some instances, it is also possible to employ a slurry containing salt such as NaCl and/or KCl though solutions are preferred. The coolant may be refrigerated to a temperature below 0° C., typically below −5° C. to −80° C. Refrigeration may be effected by well-known techniques such as passing the coolant over low temperature pipes and through compressors. A variety of refrigerating techniques well known to the art are employable.

FIGURE 4 illustrates an embodiment wherein cavity $\mathbf{7^3}$ intersects the area of the shaft. According to the drawing, the introduction holes $\mathbf{2^3}$ and withdrawal holes $\mathbf{5^3}$ are disposed outside the perimeter of the shaft region $\mathbf{1^3}$. Cavity $\mathbf{7^3}$ is as easily developed by providing a hole in the center of shaft zone $\mathbf{1^3}$ and by well known solution mining techniques, as hereinbefore described, dissolving a low height cavity, typically 50 to 200 feet in diameter, centered on the proposed shaft. Bore holes $\mathbf{2^3}$ and $\mathbf{5^3}$ are then provided. The initial bore hole is normally removed prior to excavation.

In the development of the cavity as illustrated in FIGURES 1 through 4 it is desirable to introduce an inert liquid having a specific gravity less than that of the extractant. Suitable materials include liquid hydrocarbons such as petroleum or mineral oils. These materials when introduced as described in U.S. Patent No. 3,096,969 cause lateral expansion of the cavity without significant vertical expansion. As a result thereof, a narrow passage with small depth is developed thereby avoiding excessive residence time of the coolant in the cavity on its circulation therethrough. Though less preferable than liquid hydrocarbons for this purpose, inert gas or air may also be employed.

This invention includes within its scope cavities developed by methods other than solution extraction. The development of a communicating passage between the introduction and withdrawal bore holes can also be achieved by well known hydraulic fracturing techniques. The size of a fracture, in a shale deposit, for example, may be increased by introducing thereto mineral acids such as HCl or H_2SO_4 thereby providing for adequate flow rates between the introduction and the withdrawal holes. In a clay band, communication between the introduction and withdrawal holes can be achieved by fracturing, wetting the clay band and removing clay dispersed in water or by high energy penetration with well known techniques including sandblasting. It is usually desirable that the cavity or passage be of low height, preferably about 1 to about 10 feet high although larger cavities are operable.

If the subterranean passage is constructed well below the proposed mining level, it can be left without further attention after the freezing operation has been terminated. The passage is preferably filled with ore or concrete when the refrigeration system is no longer needed. Cement and similar materials are readily pumped into the passage.

If the connecting cavity intersects the shaft area, it is sometimes desirable to drain the cavity of coolant after the shaft has reached a level just above the cavity. The shaft is then continued through the cavity, preferably sufficiently rapidly that the freeze area remains substantially frozen. A water or acid impermeable wall is then constructed around the portion of the shaft extending through the cavity. The refrigeration system is then put back into operation if desired. Alternatively the entire section of shaft traversing water-bearing material is suitably encased to prevent seepage. In that event the cavity is desirably filled and refrigeration discontinued.

Although it is usually desirable to seal the shaft against seepage of water to obviate the need for freezing the water-bearing formation, it is within contemplation that the refrigeration operation be continued while mining or other work, e.g., construction, proceeds.

Though the instant invention has been described with reference to certain specific embodiments, it is not limited thereto unless these limitations are found in the claims.

We claim:

1. In the development of a shaft in an earth formation, which formation contains a water-bearing stratum, the process of freezing the water-bearing stratum adjacent a selected shaft zone passing therethrough which comprises providing a plurality of cased introduction holes in a selected portion about said zone but out of contact therewith which holes extend through and below said water-bearing stratum and openly communicate with a cavity below said stratum, providing a cased withdrawal hole out of contact with said zone in open communication with said cavity and sufficiently removed from the introduction holes to be out of substantial heat transfer relationship therewith, feeding a liquid having a temperature below 0° C. through said introduction holes with flow through the selected portion into said cavity and withdrawing liquid from said cavity through said withdrawal hole until said selected portion is frozen.

2. The process of claim 1 wherein there is provided a plurality of cased withdrawal holes of the type of said cased withdrawal hole out of contact with said zone.

3. The process of claim 1 wherein the initial quantity of liquid introduced to said introduction hole has a temperature below −20° C.

4. The process of claim 1 wherein the cavity is a single cavity openly connected to each of said introduction holes and out of contact with the shaft zone.

5. The process of claim 1 wherein the cavity is provided in a limestone deposit.

6. The process of claim 1 wherein the cavity is provided in a deposit of mineable minerals and the shaft zone extends into said deposit.

7. The process of freezing a subterranean water-bearing stratum to prevent flooding of a selected shaft zone passing therethrough to a mineral deposit located below said stratum which comprises providing a plurality of cased holes from above through selected portions of said stratum and within 2 to 100 feet of the periphery of the shaft zone, said holes terminating below said stratum in a formation containing extractable naturally occurring substances, feeding liquid extractant to said substances through the holes to extract said substances from said formation and removing extracted substances from said formation to form a cavity below said stratum therein, providing a further cased hole through the water-bearing stratum in open communication with said cavity further removed from the shaft zone than the first named holes, and sufficiently removed from the first named holes to be out of substantial heat transfer relationship therewith, forwarding liquid at below 0° C. through the first named holes with flow through said selected portions into the cavity and withdrawing said liquid from the cavity through the second named hole until the water-bearing stratum adjacent the shaft zone is frozen.

8. The process of claim 7 wherein there is provided a plurality of withdrawal holes of the type of said further cased hole.

9. The process of claim 7 wherein the withdrawal hole and the introduction holes extend into the same formation and liquid extractant is simultaneously fed to the formation through the withdrawal and introduction holes until the cavity formed under said withdrawal hole openly connects with a cavity formed under an introduction hole.

10. The process of claim 7 wherein said formation predominates in limestone and the liquid extractant is a strong mineral acid.

11. The process of claim 7 wherein said formation is said mineral deposit and the extractant is water.

12. The process of claim 7 wherein the mineral deposit is rich in KCl and NaCl.

13. The process of freezing a subterranean water-bearing stratum to prevent flooding of a selected shaft zone passing therethrough to a mineral deposit located beneath the water-bearing stratum which comprises providing a cased hole through said stratum out of contact with but within 100 feet from the periphery of the selected zone to a formation below said stratum containing extractable substances, feeding a liquid extractant to said substances through said cased hole and removing extracted substances from said formation through said hole to form in said formation a cavity which approaches but is out of contact with the selected zone, providing a plurality of cased holes spaced about but out of contact with the periphery of the selected zone, said second named holes extending through the stratum and in open communication with the cavity and being closer to the periphery of the zone than the said first named hole and sufficiently removed from said first named hole to be out of substantial heat transfer relationship therewith and thereafter passing liquid with a temperature below 0° C. through said second named holes with flow through said stratum into said cavity and withdrawing said liquid from

said cavity through said first named hole until said water-bearing stratum is frozen.

14. A method of freezing a selected portion of a subterranean water-bearing stratum which comprises establishing a cavity under a level where water is disposed, establishing a cased hole through said portion of said stratum to openly communicate with said cavity, establishing a further cased hole through said stratum in open communication with said cavity, said further cased hole being sufficiently removed from the first named cased hole to be out of substantial heat transfer relationship therewith, feeding a liquid having a temperature below 0° C. through the first named hole with flow through said selected portion into the cavity and withdrawing said liquid from the cavity through said further hole until said selected portion is frozen.

15. The method of claim **14** wherein there are established a plurality of said cavities spaced around the perimeter of a selected zone which extends through said selected portion of said water-bearing stratum wherein each of said cavities is provided with said first and second named cased holes in open communication therewith and said liquid is fed to each cavity through at least one cased hole of the type of said first named cased hole and withdrawn from each cavity through at least one further cased hole of the type of said second named cased hole.

16. The method of claim **15** wherein the cased hole through which the liquid is withdrawn from each cavity is further removed from the selected zone than is the cased hole through which the liquid is introduced to that cavity.

17. A method of freezing a selected portion of a subterranean water-bearing stratum which comprises establishing a cavity under a level where water is disposed by leaching components of the surrounding formation into an aqueous medium and removing said medium from said formation, establishing a cased hole through said portion of said stratum to communicate with said cavity, establishing a further cased hole through said stratum to openly communicate with said cavity, said further cased hole being sufficiently removed from the first named cased hole to be out of substantial heat transfer relationship therewith, feeding a liquid with a temperature below 0° C. through the first named cased hole with flow through said selected portion into the cavity and withdrawing liquid from said cavity through said further cased hole until said selected portion is frozen.

18. The method of claim **17** wherein the aqueous medium contains a mineral acid.

19. In the method of protecting a shaft sunk through a water-bearing stratum from being flooded with water from said stratum, the improvement which comprises passing liquid coolant, initially at below 0° C., down through said stratum into a cavity located beneath said

stratum by feeding said liquid through a plurality of cased holes established in the path of flow of said water flooding said shaft and extending openly into said cavity, removing said liquid from the cavity through a cased hole established in open connection with the cavity and extending through the stratum, said cased hole being sufficiently removed from said first named holes to be substantially out of heat transfer relationship therewith and continuing the feeding and removal of said fluid until said stratum adjacent said shaft is frozen thereby preventing flooding of said shaft.

20. The method of claim **19** wherein said liquid is removed from the cavity through a cased hole openly connected with said cavity and further removed from the shaft than the said plurality of cased holes through which it was introduced to the cavity.

21. A method of freezing a selected zone extending through a subterranean water-bearing stratum which comprises establishing beneath a level where water is disposed a subterranean passage which intersects said zone, establishing a cased hole extending through said stratum and openly communicating with said passage, establishing a further cased hole sufficiently removed from the first-named cased hole to be out of substantial heat transfer relationship therewith, said further cased hole extending through said stratum and openly communicating with said passage, feeding a liquid having a temperature below 0° C. through the first-named hole with flow through said stratum into the passage and withdrawing said liquid from said passage through said further cased hole until said selected zone is frozen.

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