A hydraulic borehole mining system controlled and operated above-ground includes a high-pressure cutting nozzle that is delivered to an underground resource body through a relatively small diameter borehole. A series of water and air fluid streams at various pressures are delivered to the resource body, and the target resource is disaggregated and/or fluidized and conveyed back to surface via the hydraulic borehole mining pipe which serves as the conveyor of the system. The mining pipe is used to transport a high-pressure stream of combined air and water fluids that have been directed and aligned into laminar flow to a focused water jet cutting head. The central bore of the mining pipe brings the slurried resource to the surface. The mining pipe transports the slurry via hydraulic airlift, fluid eduction or both.

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HYDRAULIC BOREHOLE MINING SYSTEM AND METHOD

CROSS-REFERENCE TO A RELATED APPLICATION

This application claims the benefit of US Provisional Application Serial No. 61/891,674, filed on October 16, 2013 and U.S. Non-Provisional Application No. 14/512,649 filed October 13, 2014. The entire disclosure of US Provisional Application Serial No. 61/891,674 and U.S. Non-Provisional Application No. 14/512,649 is incorporated herein by reference.

FIELD OF THE INVENTION

The present application relates to the field of subterranean hydraulic borehole mining. More specifically, the present invention relates to a new and novel high pressure system and method to perform economic, high production, continuous commercial mining by hydraulic borehole mining within a target ore body either in fully submerged conditions below the water table or at full atmospheric conditions.

BACKGROUND OF THE INVENTION

In situ hydraulic borehole mining equipment and techniques have been patented in the past for applications that include the mining of uranium, phosphate and heavy oil resource bodies, such as U.S. Patent No. 4,915,452 issued to Dibble; U.S. Patent No. 4,296,970 issued to Hodges; and U.S. Patent No. 4,348,058 issued to Coakley et al. However, the mining systems and methods in these representative disclosures do not effectively address the fluid dynamics associated with maximizing effective jet horsepower, do not provide an economical alternative for mining in an isolated flooded environment, and do not effectively address the ability to efficiently lift the resource to the surface. These prior patents have defined equipment designed solely to lift ore back to the surface by the use of a high-pressure eduction system. Notwithstanding the advances made by these inventions, to date, no prior art hydraulic mining system has reached commercial success because of the ineffective utilization of fluids and the sub-optimization of production. Prior art systems do not fully integrate the critical components of hydraulic borehole mining to optimize reach and production rates on the one hand and minimize energy consumption on the other. Thus, continual economic commercial production rates have not been achieved, and the operating costs are too high to effectively replace conventional commercial mining systems and techniques.

Other problems associated with prior art mining systems are related to the mining pipe itself. The thread connections intermediate various sections of the mining pipe are prone to
galling and eventually become unusable. With the externally flanged connections of the
system invention, the problem of galling of threads is eliminated, inasmuch as the threads
interconnecting the sections have been eliminated. In a threaded connection with multiple
telescoping pipes, several sets of threads must be properly aligned in order to make up the
mining string. Even with small misalignments, threads become galled, rendering a piece of
mining pipe unusable. With the six string of the subject invention (five pipes down and one
return), the pipe is aligned, put into place and assembled together with nuts and bolts, virtually eliminating any chance of damaging the mining pipe sections.

Another problem associated with prior art mining systems is the tendency to collect
oversized particles in the bottom of the cavity. With prior art systems, when the system
becomes blocked, advancement stops, requiring tripping out of the hole and drilling the rock
fragments up by conventional methods, which severely affects operating economics.

Non-turbid lamination of the water flow to the jet is one component of the subject
invention in terms of ultimate production and reach of the jet in the cavern in both
atmospheric and submerged conditions.

Hydraulic borehole mining has several advantages over conventional mining
techniques. One of the key attributes that is exploited through the borehole mining technique
is the ability to selectively target and mine high grade resources. With hydraulic borehole
mining, the highest-grade section of the resources can be selectively mined and the remaining
lower grade resources are maintained in place. With traditional mining techniques, the
overburden is removed or worked around in order to access the targeted resource. The usual
expense and dilution of the economics of the project can render the project economically
unfeasible. The use of the subject invention and associated techniques allows a small
borehole to be drilled into the resource body, thereby permitting the target ore to be efficiently
and economically mined and moved to surface.

The environmental impact of an underground hydraulic borehole mining process is
exponentially less than that of a conventional open pit mining operation. Highly mobile
equipment deployable at any angle on commercially available modern drilling rigs allows
high accessibility to horizontal surface based, high slope and marine based operations. Small-
scale equipment used in the process minimizes site impact and decreases mining risk of
groundwater and surface contamination by cased isolation of the mining system and effective
protection of groundwater. Leaching of resources such as uranium or contaminated fluids or
acids such as those generated through oil sands or heavy minerals mining is minimized, if not
completely eliminated. A unique aspect of the system herein disclosed is that, compared to prior art systems, it can operate both in a fully submerged state and in an atmospheric state. Operating in an atmospheric state extends the reach in certain geology by increasing net delivered horsepower.

In some cases, total elimination of open pit access allows safe access to the resource. The effective mining of the resource can allow stripping the target components within the ore, such as the ablation of U308 particles from sandstone or stripping target minerals from mineral sands and the corresponding reinjection of the waste tails in situ by blended sealing with cementitious grout. Effectively, remediation costs and requirements are significantly reduced, less overburden is moved, less in situ groundwater is affected, less surface impact is created and the carbon footprint of mining operations using the invention is greatly reduced compared to conventional mining operations or prior hydraulic borehole mining technology. Personnel head count can be reduced and exposure to high-risk ore such as uranium can be greatly reduced by effective and economic commercial hydraulic borehole mining. It is not necessary to expose personnel to radiation risk underground. Moreover, the invention provides closed loop fluid circulation limiting oxygenation of the resource. This reduces environmental exposure of radiation, salt water and acid onto the surface and in situ mining sector.

Within the United States and in other countries around the world a vast inventory of projects exist that have either reached the end of their known economic mining life, or that cannot be initiated into production due to unachievable economics or operational or technical inaccessibility. This invention with the complete modernization of new, conceptual and proven hydraulic engineering components will provide a new opportunity to reestablish prior mined resource areas, to create new jobs by economic resource creation and to enrich both private industry and government owned resource bases. Further, this invention will allow the establishment of a new realm of mining potential in environmentally sensitive areas which are not accessible currently because of destructive surface mining or risk of exposure to undesirable mining circumstances. Additionally, the mobility and accessibility of this invention allows the resource owner to target smaller reserves with more discerning accuracy of mining, thereby increasing established resource and reducing capital and regional impact.

Resource body types exist, such as metallurgical coal seams in steeply dipping planes along the environmentally sensitive slope of the Rockies, the steep hills of Appalachia, and the ultra-heavy oil reserves of west Texas and California that are not currently minable. The shale oil reserves on the Eastern Rockies slopes are sub-economic to conventional mining.
The deep in situ uranium deposits in New Mexico, Colorado and Texas and the kaolin and phosphate deposits of the Southeastern states all have development, reserve and resource potential beneficial to private industry and government with the effective deployment of this system and apparatus. The Kimberlite reserves of Saskatchewan, Canada cannot be developed with conventional mining methods, yet exist as the largest Kimberlite reserves in the world. Kimberlite pipes which only allow fractional accessibility through conventional mining, Kimberlite and Lamprolite pipes in Australia and South Africa that have reached economic limit because dewatering costs are too high or the size of the pipes and the incline of the hanging walls are too steep for conventional mining, all may be accessed by the system and methods herein disclosed. The same may be said of millions of tons of other known resources that cannot be mined or declared as economic reserves because the ore is inaccessible due to high water tables and or excessively steep access ramps. This invention allows the resource owner to drill deep into pipes and target high-grade ores and minerals selectively and up to depths never achievable with conventional mining in certain conditions. Offshore granular resources such as tin mining can be enhanced with the invention where conventional dredges cannot access the resource through deep overburden. Technical accessibility with the invention proves a highly desirable effect on mining potential with low disturbance.

In the hydrocarbon resource sector, the system allows further development of oil shales, oil sands, oil rock and gas shales by cavity creation. Cavity creation allows significant opening of the natural fractures of the rock and may be used as a replacement to hydraulic fracturing or "fracking." This advancement alone may have significant impact on the conventional oil industry in areas where fracking creates potential for disturbance or is completely banned.

The nature of the system allows the operator to excavate the oil in situ and transport the oil bearing rock to the surface. The subject invention will allow unique access to depleting fields that have significant quantities of oil not currently economically recoverable with known technology. The mining system of the present invention could be used in countries where fracking is completely banned and substitute shallow heavy oil deposits exist.

**SUMMARY OF THE INVENTION**

The subject invention provides an economic mining alternative to the energy consumption and fluid requirements of the prior art having sole eduction systems, and utilizes hydraulic airlift and/or eductor system technology to lift the resource to the surface through a vertical lift section of the system. The annular fluid of the system and an inner bore reverse
circulation system differential allow an operator to inject a small amount of low pressure air into the return fluid column, thereby reducing its density and creating a vacuum at the system inlet to efficiently lift most resources to surface.

When compared to prior art stand-alone eductors, the airlift system of the subject invention can operate very efficiently with very limited energy. The reduced horsepower and diesel consumption during operation of the mining system of the present invention creates dramatic capital and operating cost savings.

The eduction system is an effective method to return the slurry to the surface. In some conditions such as with horizontal mining, eduction works in conjunction with the other components of the mining system. However, as a stand-alone method of lifting, the energy requirements are very high and require that a very high ratio of fluid and pressure be circulated to the bottom of the well bore to educt the disaggregated resource material back to the surface. The subject invention addresses this and other problems associated with prior art systems by being designed to work while jetting in atmospheric conditions or in submerged conditions. The eduction boost on the system is provided and allows access to long horizontal resource beds from the surface by providing a low pressure fluid eductor at the inlet of the miner to push the slurry coaxially through the horizontal section of the mining pipe into the vertical section of the well bore and for the hydraulic airlift at that point to boost the fluid the rest of the way to the surface through differential hydraulic pressure.

The pipe connections within the system herein disclosed address the galling problems noted above. The high-pressure fluid streams have no tolerance for leakage. The jetting connections operate at extremely high pressures (up to 10,000 psi), and the fluid must remain fully, safely and properly sealed for the entire length of the mining system. A pressure or fluid loss at a connection is intolerable due to the safety risk at high pressures and the need to control jet volumes and consistent delivery pressure at the outlet.

More particularly, the method of the subject invention involves economically mining subterranean resource in situ comprising the steps of drilling a surface hole into subsurface material to access the target resource, injecting high pressure fluid via a borehole mining tool into the resource thereby forming a jet to disaggregate the subsurface material creating a slurry of solids and fluid, injecting a gaseous fluid into the slurry to encapsulate and accelerate the high pressure fluid jet, injecting a large volume of water at low pressure into the slurry for eduction to mix with and transport the slurry, injecting low pressure air into an
airlift sub to create suction whereby the slurry is lifted to the surface, separating solids and water at the surface; and optionally recycling the water for reuse in the method.

Further, the subject invention involves, a borehole mining system including at least one multi-conductor high pressure swivel for redirecting high pressure fluids of both air and water in a high pressure section through the system and to pass a generated slurry though the center bore, a low pressure swivel for redirecting the low pressure slurry at the surface, an air lift sub for assisting the return of the slurry to the surface, a lamination tool within the mining pipe for placing the high pressure water into laminar flow, a monitor pipe that maintains the laminar flow of the water from the monitor pipe to the single flow into the quartic-straight jet nozzle, an eductor system for mixing and returning the slurry to the surface, a plurality of internal flush connection subs joining the high pressure section, a turning section including a plurality of splitter vanes establishing and for maintaining the laminar flow of the water during a turn into a nozzle; and a fluid/air shrouding system.

The borehole mining system of the subject invention has a mining pipe with multiple passages, at least one of said passage being a high pressure section for redirecting a high pressure fluid water through the system; the high pressure section includes a first section with a pair of interior vanes positioned perpendicular to each other, and the interior vanes establish a laminar flow of the fluid within the first section. A second section is connected to the first section for receiving the laminar flow and turning the laminar flow to a different direction. The second section has a plurality of adjacent parallel passageways, each of the adjacent passageways conveying a different volume of said fluid, so that the laminar flow of said fluid is maintained in its flow through the second section. The passageway that is interior to its adjacent passageway will carries less volume of fluid because it is shorter and smaller, so that the flow of water through the turning section remains the same regardless of the passageway and thus maintains the laminar flow. The interior vanes that establish the laminar flow can establish a minimum of three or four passageways, and more, dependent on the size of the pipe. The interior vanes may be replaceable for better and longer life, as may be the blades of the turning section.

The subject invention operates at the torque and stress level required for drilling operations while mining. The system has a purpose-designed eductor drilling bit that educts right from the bit head itself. This attribute allows an operator to progress the well with the mining systems of the present invention compared to prior systems that had to be removed from the well. In addition, the subject system allows for the removal of material at the bottom of the well and not further up the drill string in the sidewall of the pipe as before. The inlet up
the side wall of the pipeline does not allow the continuous mining of soft formation caving ores such as mineral sands because the prior art systems did not allow advancement while mining.

The subject invention aligns the two parallel high-pressure water supply lines from the pumps at surface. The water flow travels in parallel to a point in the mining pipe where it is introduced to four laminar flow chambers created by sectionalized vanes 9 meters long that align the fluid into laminar flow. The two laminar flow pipes connect to the mining head itself. A block co-joins the fluids and maintains the laminar flow to the delivery section of the miner where the jet exits.

In order to turn the very high pressure flow 90 degrees to exit out of the jet to cut the sidewall and thus create the cavity mined, the system of the subject invention must maintain the alignment of the flow while in lamination in order to maximize the distance and the effectiveness of the jet. To do this, the subject invention utilizes a turning vane block that has inset replaceable turning vanes that turn the high-pressure high volume flow without creating turbidity or losing lamination. The subject borehole mining invention uses a set of replaceable turning vanes positioned prior to the chamber of the monitor jet. The current invention utilizes replaceable and serviceable blade sections that may be quickly and economically repaired for ongoing operations. When the blades become damaged over time by the passing of fluid over them, they may be removed by unbolting the housing and replacing them. Prior art designs often resulted in a pipe split which had to be welded back together or which was otherwise unserviceable and disposable. A set of removable turning splitter vanes further enhances the economics of the system, creates more overall efficiency and requires fewer replacement parts to maintain day-to-day operation of the equipment.

The hydraulic borehole mining process of the subject invention can be summarized as follows: a suitably sized hole is drilled to convey the borehole mining system to the top of the resources to be mined; that surface hole is then cased if necessary, and cemented as known in the art to provide stability and to protect groundwater and resource leaching; a hole is then drilled through the resource body; a mining pipe with multiple passages with a jet nozzle and a slurry recovery system is then lowered into the borehole. A high-pressure fluid pumping system is connected to the mining string and high pressure fluid is pumped down the string and out of the nozzle at the cutting face. The high-pressure fluid stream interacts with the rock face down hole disaggregating the rock and putting the particles into a slurried suspension; this slurry is then recovered through a piping system and returned to the surface,
where the rock that is recovered will be processed and the mining fluid is returned to be pumped down hole again.

Another component of this invention is the ability to multi-task with up to six separate lines comprising the mining pipe. One line is the air/fluid shroud that can be utilized to protect the water jet. This shroud is a jet of high-pressure air or fluid (or a mixture of both) that is formed down hole to surround the high pressure water jet as it exits the nozzle. This shroud effectively provides an encasement and protection of the jet, whether cutting with fluids at atmosphere or submerged. In either case, the air and optional fluid increase the focus of the water jet and, hence, increases delivery jet horsepower on the target. Depending on the flow requirements, multiple lines can be used for jetting fluid, or, alternately, multiple jets could be used. In addition, air lift can be used in a line to use air lift for the primary method of slurry recovery or as a supplement to eduction. The mining pipe also has the ability to provide a return line for the slurry created while mining. With a multiple line/passage mining pipe the operator has the option for a specific configuration for a specific application that can be changed if required, all while only requiring one mining pipe to be installed into a horizontal or vertical wellbore.

The mining system of the present invention mines hydraulically at significant depth at all angles from true vertical depth to a completely horizontal setting through a narrow diameter surface-drilled hole in both atmospheric and in submerged conditions. High pressure mining fluid is conveyed through the system to the cutting nozzle down the hole. This interaction between the mining fluid and the target rock face disaggregates and slurrifies it and it is returned to the surface via specific return elements in the system.

This invention can be utilized to economically and efficiently mine resources that sit from 0 to 90 degrees from the vertical. This hydraulic borehole mining system can be utilized in resource bodies that are submerged or that are dewatered. The system utilizes a fluid/air-shroud around the jet to increase the hydraulic horsepower to the rock face when the tool is utilized in a submerged or atmospheric environment. The entire process occurs in a closed loop system, from the high-pressure water delivery elements from the surface down the borehole to the return elements back up into the surface processing facilities. The surface annulus is sealed and connected to a pump that boosts the pressure on the annulus space, thereby aiding in the return of the slurry to the surface.

This system effectively utilizes principals of fluid engineering and differential dynamics both by maximizing effective hydraulic horsepower and fluid density properties by lamination
of fluid flow through the mining system down the well bore and though a tight radius turn of
the jet stream. A shroud of a high-pressure air or fluid stream (or a mixture of both) encircling
the water jet stream protects the fluid jet generated by the laminated focused flow of mining
fluid. The fluid jet shroud has proven effective to consolidate and protect the fluid stream and
increase the effective jet horsepower both at atmosphere and under submerged conditions.

This mining system is designed to operate within the plane of the ore body that yields
the greatest resource production at any angle from vertical to completely horizontal. The
system is deployed either by directionally controlled drilling or vertically controlled stabilized
drilling.

All of the elements of this mining system are designed to maximize fluid flow
efficiency both down and up the wellbore. This fluid circulation with the air supported
laminar hydraulic jet and the return to surface using differential pressure allows a significant
reduction in equipment, energy and costs from any past versions of hydraulic borehole mining
systems. Minimization of economics and reduction of the operating footprint and personnel
prove to define commercial economics in multiple target ore types.

**BRIEF DESCRIPTION OF THE DRAWINGS**

**Fig. 1** is a general schematic of a hydraulic borehole mining system in accordance with
an embodiment;

**Fig. 2** is a general overview of the hydraulic borehole mining string of the system of
Fig. 1;

**Figs. 3(a)-(f)** are detailed drawings of the monitor subassembly for the hydraulic
borehole mining string including a Y design laminar flow joint, turning vane block, nozzle
holder and nozzle;

**Fig. 4** is a drawing of the low pressure and high pressure combination swivel;

**Figs. 5(a) and (b)** are drawings of the flex joint insert for horizontal hydraulic borehole
mining applications;

**Figs. 6(a) and (b)** are drawings of a section of mining pipe;

**Fig. 7 (a) and (b)** are drawings of a laminar flow insert mining pipe;

**Figs. 8(a)-(d)** are drawings of an airlift subassembly;

**Figs. 9(a)-(c)** are drawings of an internally flush high pressure connection assembly;

**Fig. 10** is a drawing of a bit assembly;
Fig. 11 is a drawing of an eductor bit sub assembly; and

Fig. 12(a) and (b) show a drill rod assembly with connection subs.

DETAILED DESCRIPTION OF THE INVENTION

Referring now to Fig. 1, a system and a process of hydraulic borehole mining for a subterranean resource in accordance with the present invention is described in detail. A rig shown generally at 1 is brought to the site, situated at a preferred location at the site, and operated to drill a well (or wellbore, as the term is used in the art) to the top of the resource body. The wellbore may be drilled at any angle from vertical to horizontal depending upon the geotechnical mining conditions down-hole and the structure of the ore body itself. A casing string 3, if required, is then run into the initial bore and cemented into position to give strength to the wellbore. A conventional drill string is then fed into the casing string, and a pilot hole is drilled through the resource body. The conventional drilling string (not shown) is thereafter removed from the hole.

Referring now to Figs. 2 and 6(a)-(b), a mining string 5 is illustrated in greater detail. The mining string is run into the wellbore and includes an eductor bit 8 positioned at the bottom end 10 of the string and attached to a monitor pipe 12, which houses the quartic-straight jet nozzle 15 (Fig. 3(e) and (f)), the turning vanes 18 (Fig. 3(c)), and the integrated Y design laminar flow joint on monitor pipe 12 (Fig. 3(a) and (b)), all of which will be described in greater detail below. The monitor pipe 12 is connected to the mining string 5 that extends from the surface and the rig floor down to the subterranean resource deposit 21 (Fig. 1). The mining string includes swivels 22, 24 (Fig. 4). At swivel 22, the connections are made from the mining string to the surface equipment at 120. The swivels consist of a set of two swivels, one high pressure 24 and one low pressure 22; the interconnections of which provide all of the fluid connections needed for the process. The high pressure swivel, which sits on the bottom of the two swivels, takes the high pressure feeds of water for the quartic-straight jet nozzle, the air to the air lift system, fluid for the eductor, and the air or fluid to the air/fluid shroud, and sends them down the respective lines in the mining pipe to the attachments down the string. The low pressure swivel 22 that is attached above the high pressure swivel provides a passageway 130 or a return line for the slurry to return up the hole via the 90 degree turn into the return line, thereby directing the slurry to one or more surface processing facilities, generally shown at 26 in Fig. 1. A unique and novel feature of the system of the present invention is the significantly enhanced ease of maintenance and efficiency of operation as compared to any prior art systems and methods. By way of example and not of limitation,
maintenance of either the high or the low pressure side of the system will not involve
replacing parts or tearing down the other side, and vice versa.

As best shown in Fig. 1, the configuration of the surface portion of the mining system is
illustrated. The surface equipment includes two high-pressure, high-volume jet mining pumps
(not shown), which deliver water down hole via the swivel and high pressure lines 32. An air
compressor delivers air to the swivel via high and low pressure lines 36 to be delivered down
hole to an air/fluid shroud 38 around a quartic-straight jet nozzle 15 and the airlift sub 100
shown in Fig 8, both of which are shown in Fig 3. When conditions dictate, the high pressure
airline that forms the air shroud can be connected instead to a pump that supplies fluids of
different densities to the shroud nozzle to aid in the hydraulic horsepower of the tool.
Referring back to Fig. 1, a lower pressure water pump delivers water to the eductor bit 8 and
to the backside of the well head via low-pressure water line 44 to keep the surface hole full of
water. The supply of low pressure water to the backside optionally may be forced in past a
seal, introducing an additional amount of pressure and force to the backside of the pipe. This
additional force above the weight of the column of water on the backside gives a boost to the
recovery system by essentially forcing fluid under pressure up the mining string's lower
density return line and thereafter to surface.

As shown in Fig. 1, the return line runs from the swivel to a dewatering system via a
low-pressure slurry return line 50. This portion of the system removes the water from the
resource and returns the water to a dirty water storage pond or tank. A storage facility 56 is
used to store the dewatered resource while awaiting further processing by the mine. The water
from the dewatering system then flows to a settling pond where any fines that have collected
into the water are permitted to settle before flowing into a clean water storage area. The clean
water storage area holds the clean water, which feeds all of the pumps.

The clean water is boosted into the high pressure pumps and then pressurized and
pumped into the high pressure mining swivel 24 (Fig. 2, 4), where it is turned 90 degrees and
down the mining string 5 through two external lines 62, 64 on the mining pipe, as best shown
in Fig 6. Each pump feeds one of the lines via high-pressure lines 32. These lines are
connected to the swivel 24 at flanges 66 with full bore fittings and then run the length of the
pipe via stabilizers.

Referring to Figs 9(a)-(d) and Figs. 12(a)-(b), the mining pipe connections utilize full
flow connection subs 70 at each of the quint external lines which provides a high pressure seal
between the mining pipe sections that make up string 5 via special high pressure, expandable
O-rings 72 seated in grooves 74 formed in the sub 70 (Fig 9(b) and 9(c)). Each of the subs includes an external diameter d (Fig 9(b)) which fits inside a corresponding mating flange (not shown) on the mining pipe. This novel configuration allows for the full inside diameter (internally flush) of the external lines of the mining pipe to be maintained in the connection sub. The connection subs are utilized in the connection of the individual segments of the entire mining pipe (Fig 2), the connection of the airlift sub (Fig 8(c) and (d)) and the connection of the monitor pipe 12 (Fig 3(a) and (b)). Due to the internally flush - full bore, restriction-free structure of the subs, there is less of a pressure drop in the high pressure lines at the connections, an advantage which manifests itself over a large number of connections in a string, where the pressure drop over the overall distance would be significant.

The last 9 meters of the mining pipe in the string contain a pair of laminar flow vanes 80 positioned perpendicular to one another and which are illustrated in greater detail in Fig 7(a). Each pipe includes two laminar sections 82 which are structured and arranged to preliminarily align the otherwise turbid flow of the water into a laminar flow stream configuration, thereby providing increased hydraulic horsepower to the jet stream. The laminar flow is established utilizing the four sections to split and align the flow. The vanes 80 are formed of a suitable material such as steel and are positioned securely in the high pressure water lines of the mining pipe as shown in Fig. 7, the vanes being sealed in place by means of a high pressure o ring seal 84 in a housing 86 positioned inside of the lines. This o ring seal is extremely tight and fixes the units to minimize resonance within the pipe. The vanes 80 are designed for easy and quick replacement by withdrawal of the worn vanes and insertion of new vanes into slots 81.

Referring to Fig. 3(a) and (b), the high pressure water lines feed the laminar water flow to the monitor pipe 12 where they are joined to a laminar flow block 88 (Fig 3(a), which ensures that laminar flow is maintained while the water is joined and then forced through the turning vanes 18 (Fig 3(c) and (d) which split the flow and maintain it in a laminar stream around the bend without introducing turbidity. These vanes are spaced out unevenly at predetermined spacing distances based on the flow around the 90 degree turn into the quartic-straight jet nozzle 15 (Figs 3(a) and (f). The variation in the distances between the vanes is a function of the speed, drag and flow of the water around the bend. Thus the interior passageway 16 allows less volume of water to pass, being smaller in size than the exterior passageway 17, which is larger. As the passageways progress from interior of the block side to the exterior, they become successively larger in volume and carry more water, thereby equalizing the flow of water through the block. Each passageway is thereby larger than the
adjacent passageway as one goes from the interior of the block turn to the exterior. In this manner the laminar flow of water in each passageway through the laminar flow block 88 is maintained by allowing the same amount of water through the block throughout the ninety degree turn, thereby reducing or eliminating turbulence in the flow at the block exit. As a result, more water at a higher velocity can be provided through the system because of the continuation of the laminar flow. The turning vanes 18 are designed to work with the anticipated cutting fluid and the total anticipated volume of flow through the jet.

Fig. 7(b) Illustrates the ease with which the nozzle may be easily field serviced for quick servicing and/or replacement of the jet to adjust the focus distance in different types of resources. The turning splitter vanes are connected to the quartic-straight jet nozzle 15 by bolts. The quartic-straight jet nozzle delivers the laminar flow into a focused jet through the nozzle orifice 90 delivering a high pressure, high volume stream of fluid at supersonic velocity into the rock face. An air/fluid shroud surrounds the water jet exiting the quartic-straight jet nozzle. This air/fluid shroud is created by high pressure air or a high-pressure fluid delivered from the surface (Fig. 1) through the high-pressure swivel 24, via an external line on the mining pipe 5, through the monitor pipe 12 and into the shroud. The air/fluid is then delivered into the air/fluid shroud that focuses the air/fluid in a large diameter nozzle that encircles the high pressure quartic-straight jet with nozzle orifice 90. The air/fluid shroud effectively surrounds the high pressure jet and increases the distance over which the jet stays consolidated for both underwater and standard atmospheric operating environments. The shroud flow laminates and binds to the jet flow and helps to accelerate the jet flow at atmosphere. While submerged, it lowers the density of the water along the jet flow alignment, effectively increasing the hydraulic horsepower that will be acting on the ore face in both environments. A unique aspect of this feature is that it allows the system to be operated at either increased jet pressure (thus taking less time to disaggregate the rock) or, alternatively, at a lower pressure (consuming less energy) to have effectively the same force from the water jet at the rock face.

As the water jet impacts the rock face it begins to disaggregate the material. The disaggregated material mixes with the water creating a slurry stream which is then carried to the eductor bit 8 as shown in Fig. 2. The eductor bit pushes the slurry stream up a center return pipe 92 whereupon it is accelerated by the vacuum created in the mining return pipe by the combination of an airlift system or sub, as it is known in the art, 100 (illustrated in greater detail in Fig. 8(b) and the pressure applied to the outside of the mining string 5. This vacuum is created in two unique ways. First, the airlift system 100 charged by air from the compressor
34 is carried through the mining pipe via an external line 102 to the airlift sub where it terminates at the airlift housing 104. The air then escapes through even perforations in the ring within the airlift housing into the slurry return line 92 via the airlift entry ports (not shown). The tiny bubbles that are introduced at depth expand as they move up the slurry return line. The bubble expansion lowers the density in the slurry return line which causes a u-tube effect on the outside of the mining string, and fluid moves through an eductor bit opening 108 and into the mining pipe slurry return line. This suction recovers the slurry created by the quartic-straight jet nozzle 15 and the disaggregated ore.

The airlift system 100 is typically placed at depth in a vertical well at a level to maximize the lift of slurry. This is adjusted according to the type of resource. For instance, when mining Kimberlites, the depth of the airlift sub in the well is controlled closely to keep velocities of the resource lower to limit diamond breakage. For mining uranium, on the other hand, an example of ore where grain size after cutting is not monitored, the airlift housing is placed lower in the well to increase the tonnage/mining rate per hour. On horizontal wells the airlift release is generally within the vertical section of the well for lift, and the eductor pushes the cut ore through the horizontal section. Critical velocities are matched to each ore type and the direction of the well to ensure the slurry is maintained in suspension without erosion of the system. The airlift system is a significant improvement over previous systems that only incorporate a fluid eductor for the recovery of the slurry, inasmuch as the airlift system reduces the total amount of horsepower that is needed on location to drive the system. It is through this reduction of horsepower that a significant reduction of overall capital costs is attained, not only by eliminating an additional pump, but also by reducing the overall cost of the operating expenses as a result of the lower horsepower demands.

The second part of the slurry return system is the eductor bit 8 discussed above with reference to Fig. 2. The eductor bit is operated with relatively low pressure and with a high volume stream of water. This water is delivered through one of the external lines 112 on the mining pipe 5. This water is delivered to a sub assembly 110 (Fig 11), turned 180 degrees via conduit or line 112 and directed back up the inner bore of slurry return line 92 of the mining string 5, which causes a suction that draws in slurry and forces it up the hole.

As shown in Fig. 11, the slurry passes through the narrower gauge of the eductor housing while being simultaneously boosted through that section of the eductor with the clean water from the surface via external line 112. The acceleration of the fluids through the narrow section and then up the slightly larger inner bore of slurry return line 92 of the mining pipe causes a vortex and, effectively, a vacuum on the down hole side of the eductor. The two fluid
streams converging in the narrow body of the eductor accelerate and then are released into the larger return pipe diameter. The differential pressure does not allow the fluid out the bottom of the bit so it accelerates the flow up the well bore continuously. The slurry is then carried up the hole, through the high-pressure swivel 24 and through and out of the upper low-pressure return swivel 22, where it is sent to the surface dewatering facility 26 via a slurry return pipe 50, as shown in Fig. 1. A bit assembly 120 (Fig 10) can be utilized, where the slurry passes a plurality of replaceable cone teeth 122 into the slurry return line and thereafter into the mining pipe return line, as hereinabove described. This offers no additional boost to the system but helps grind slurry when required.

Each resource type dictates the specific mining strategy utilized. The formation of the mined cavity can be by drilling a pilot ahead and through the resource body and starting at the bottom of the hole and mining up or back towards the rig in the case of a horizontal well, or starting at the top of resource body and utilizing the eductor bit of the present invention to drill and mine at the same time from the top down. The competency of the formation of the target resource and the geotechnical parameters surrounding it dictates the mining approach and strategy. In either direction, the cavity is developed through the disaggregation action of the hydraulic jet and the rotation of the mining string. The string is rotated at a slow rotational speed, the speed of rotation being determined by the competency of the formation and the distance or length of the cut at any given point within the resource body. The jet is rotated sufficiently slowly to allow enough effective interaction between the hydraulic jet and the rock face to perform the disaggregation and the slurrification of the resource. The rotational speed is determined by the amount of material that is returned and sent through the dewatering facilities. The time on the ore face coupled with the combination of flow and pressure is adjusted to maximize production. As the mining string is slowly rotated, a larger and larger cavity is created. This cavity in a vertical application can be a full 360 degree circle or pillars can be left in place to support the surrounding resource as the cavity is cut. As the returns diminish, the tool string is moved vertically and another rotational pass is made. This basic technique is continued until the desired cavity is cut from the targeted zone. Several times during the process, the mining string can be dropped to the bottom and the suction system can be used to remove any slurred material that passed the mining string and fell to the bottom of the hole. Dependent on the resource being cut, an initial pass can be made without the shroud. Then, a second pass over the ore face can be made with the fluid/air shroud. The shroud system increases the effective hydraulic horsepower at the ore face, which increases the cutting distance of the tool. The entire cutting process is repeated
with the shroud on to enlarge the cavity. Upon completion of the cavity mining the entire mining string is removed from the borehole.

When the hydraulic borehole mining is performed in a high angle or horizontal application, the technique used to create the cavity can be different than that of the vertical application. In a horizontal application, the system of the instant invention is ideally drilled and directed to the bottom of the targeted resource. A pilot hole will be drilled from surface to the bottom of the targeted resource body and then horizontally out as far as reasonably possible into the formation, based on the characteristics of the formation material. The hole will be drilled out as far as possible without collapsing on top of the tool string. The drilling string will be removed and replaced with the mining string of the present invention. The mining system will be run out in the lateral direction to the end of the hole. Thereafter, the jet will be turned on. In the horizontal application, the monitor pipe will be rotated no more than 180 degrees. Since the tool is on the bottom of the resource zone, the targeted areas will be to the side and the top of the monitor pipe. In thicker resource zones, one lateral well can be mined above the other. If the competency of the resource body is low then the monitor pipe can be manipulated to perform 60-degree sweeps to either side of the tool, thereby making a bowtie pattern in the resource body. The advantage to this pattern in a low competency formation is that it permits recovery of the resource on the sides, which is facilitated by the natural subsidence of the formation over the mining string. As a section of the cavity is excavated, the mining string is slowly extracted, making the cavity larger and longer as the tool is retracted into the surface casing string. Upon completion of the cavity the mining system is removed from the hole.

Although the present invention has been described with reference to a particular embodiment thereof, it will be understood by those skilled in the art that modifications may be made without departing from the scope of the invention. Accordingly, all modifications and equivalents which are properly within the scope of the appended claims are included in the present invention.
WHAT IS CLAIMED IS:

1. A method for economically mining subterranean resource in situ comprising the steps of:
   a) drilling a surface hole into subsurface material to access the target resource;
   
   b) injecting high pressure fluid via a borehole mining tool into the resource, thereby forming a high pressure fluid jet to disaggregate the subsurface material and creating a slurry of solids and fluid;
   
   c) injecting air or fluid into the shroud to encapsulate and accelerate the high pressure fluid jet;
   
   d) injecting a high volume of water at low pressure into the slurry to mix with and transport the slurry;
   
   e) injecting gas into an airlift sub to create suction whereby the slurry is lifted to the surface; and
   
   f) separating solids and water at the surface.

2. The method of claim 1 further comprising the step of placing the high pressure fluid in a laminar flow.

3. A borehole mining system for horizontal mining of resources, comprising:
   
a mining pipe with multiple passages, at least one of said passage being a high pressure section for redirecting a high pressure fluid water through the system;
   
said high pressure section including a first section with a pair of interior vanes positioned perpendicular to each other, said interior vanes establishing a laminar flow of said fluid within said first section;
A second section connected to said first section for receiving the laminar flow, and turning the laminar flow to a different direction, said second section including a plurality of adjacent passageways, each of said adjacent passageways conveying a different volume of said fluid, whereby the laminar flow of said fluid is maintained in its flow through the second section.

4. The borehole mining system of claim 3 wherein the plurality of adjacent passageways in said second section are in parallel.

5. The borehole mining system of claim 3 wherein an interior of said passageways carries less volume of fluid than the adjacent passageway.

6. The borehole mining system of claim 3 wherein said interior vanes form four laminar flow chambers.

7. The borehole mining system of claim 3 wherein said interior vanes are replaceable.

8. The borehole mining system of claim 3 wherein said passageways are formed by replaceable blades.

9. The borehole mining system of claim 3 wherein said second section has an interior passageway and an exterior passageway, said interior passageway being shorter in length than said external passageway.
**INTERNATIONAL SEARCH REPORT**

International application No.  
PCT/US20 14/0604 15

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### A. CLASSIFICATION OF SUBJECT MATTER

- **IPC(8) - E21 B 43/29 (2015.01)**  
- **CPC - E21 B 43/29 (2015.01)**

According to International Patent Classification (IPC) or to both national classification and IPC

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### B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

- **IPC(8) - E21B 17/18, 43/29 (2001.501 )**  
- **CPC - E21B 17/2003, 21/12, 43/29 (2015.01) (keyword delimited)**

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

- USPC -37/322; 137/8, 13; 138/37, 39; 166/177.5, 222; 175/67, 213, 216; 199/17; 239/553.5; 299/17; 406/61

Electronic data base consulted during the international search (name of data base and where practicable, search terms used)

- PatBase, Google Patents, Google

Search terms used: laminar, vanes, bore, mining, jet, borehole, jet, high pressure

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### C. DOCUMENTS CONSIDERED TO BE RELEVANT

<table>
<thead>
<tr>
<th>Category</th>
<th>Citation of document, with indication, where appropriate, of the relevant passages</th>
<th>Relevant to claim No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y</td>
<td>US 4,401,345 A (ARCHIBALD) 30 August 1983 (30.08.1983) entire document</td>
<td>1-9</td>
</tr>
</tbody>
</table>

Further documents are listed in the continuation of Box C.

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* Special categories of cited documents:

- **“A”** document defining the general state of the art which is not considered to be of particular relevance
- **“E”** earlier application or patent but published on or after the international filing date
- **“L”** document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
- **“O”** document referring to an oral disclosure, use, exhibition or other means
- **“P”** document published prior to the international filing date but later than the priority date claimed
- **“T”** later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
- **“X”** document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
- **“Y”** document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
- **“Z”** document member of the same patent family

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Date of the actual completion of the international search: 12 February 2015

Date of mailing of the international search report: 02 MAR 2015

Name and mailing address of the ISA/US  
Mail Stop PCT, Attn: ISA/US, Commissioner for Patents  
P.O. Box 1450, Alexandria, Virginia 22313-1450  
Facsimile No. 571-273-3201  
Authorized officer: Blaine R. Copenheaver  
PCT Helpdesk: 571-272-4300  
PCT OSP: 571-272-2774

Form PCT/ISA2 10 (second sheet) (July 2009)
### Box No. I  Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. [ ] Claims Nos.: because they relate to subject matter not required to be searched by this Authority, namely:

2. [ ] Claims Nos.: because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. [ ] Claims Nos.: because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

### Box No. III  Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

See extra sheet.

1. [x] As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. [ ] As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.

3. [ ] As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. [ ] No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims: it is covered by claims Nos.:

**Remark on Protest**

- [ ] The additional search fees were accompanied by the applicant’s protest and, where applicable, the payment of a protest fee.
- [ ] The additional search fees were accompanied by the applicant’s protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- [x] No protest accompanied the payment of additional search fees.
This application contains the following inventions or groups of inventions which are not so linked as to form a single general inventive concept under PCT Rule 13.1. In order for all inventions to be examined, the appropriate additional examination fees need to be paid.

Group I, claims 1, 2 are drawn to a method for economically mining subterranean resource in situ.
Group II, claims 3-9 are drawn to a borehole mining system.

The inventions listed in Groups I and II do not relate to a single general inventive concept under PCT Rule 13.1, because under PCT Rule 13.2 they lack the same or corresponding special technical features for the following reasons:

The special technical features of Group I, a method for economically mining subterranean resource in situ comprising drilling a surface hole, injecting high pressure fluid via a borehole mining tool into the resource, thereby forming a high pressure fluid jet to disaggregate the subsurface material and creating a slurry of solids and fluid, injecting air or fluid into a shroud, injecting a high volume of water at low pressure into the slurry, injecting gas into an airlift sub to create suction, and separating solids and water at the surface, are not present in Group II; and the special technical features of Group II, a borehole mining system comprising a mining pipe with multiple passages, a high pressure section including a first section with a pair of interior vanes positioned perpendicular to each other, said interior vanes establishing laminar flow, a second section turning the laminar flow to a different direction, said second section including a plurality of adjacent passageways, are not present in Group I.

Groups I and II share the technical features of a mining system comprising a high pressure fluid. However, these shared technical features do not represent a contribution over the prior art. Specifically, US 4,401,345 A to Archibald teaches of a mining system (Abstract; Fig. 1) comprising a high pressure fluid (Col. 2, Lns. 56-59 regarding high pressure water).

Since none of the special technical features of the Group I and II inventions are found in more than one of the inventions, unity is lacking.