

Hydro-Blast Mining Shoots Ahead

**by
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Recent advances in subsurface hydraulic mining through small-diameter boreholes open the way to new extractive methods

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Borehole mining combines the principles of hydraulic mining, slurry mucking and rotary drilling. The borehole is drilled with conventional equipment and is cased down to the top of the mining zone. The borehole mining tool is comprised of the kelly-swivel assembly, multiple drill-pipe sections, and the jet-pump barrel assembly as shown in Fig. 1. The kelly swivel is fitted with a bail to support the mining tool. The kelly drive bushing engages the rotary table to allow the rotation of the mining tool while it is being operated. The jet-pump barrel assembly is comprised of the sidewall jet nozzles, the jet-pump assembly, the suction screen, and the tricone rock bit.

Clean fluid is pumped at high pressure through the kelly hose to the high-pressure swivel on the mining tool. The high-pressure pipe conducts the fluid down to the sidewall jet nozzles, the pump jet nozzle, and the tricone rock bit. The sidewall jet streams cut the formation and wash the cuttings down to the rock bit. High-pressure fluid issues from the water courses to clean the bit and to agitate the cuttings. Rotation of the mining tool causes the rock bit to grind any oversize material enough to permit its passage through the suction screen. High-pressure fluid issues from the pump jet nozzle to provide the lift needed to pump the slurry to the

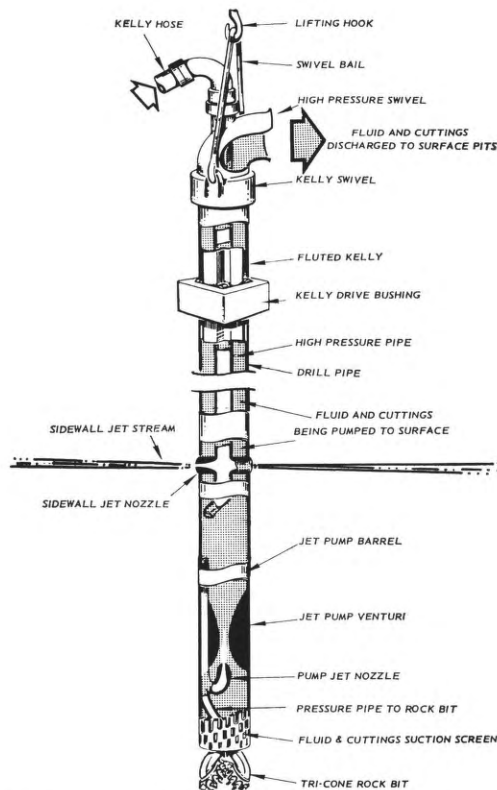


Fig. 1—Diagram of the borehole mining tool. In operation, the kelly drive bushing engages the rotary table to allow tool rotation. Sidewall jet streams cut the formation and wash the cuttings down to the rock bit.

surface. The slurry is discharged into the settling pits where the cuttings are deposited and the clean fluid is returned to the suction of the high-pressure pump.

Flow Rates Are Crucial

Preparations for borehole mining would first entail determining (1) the desired mining rate, (2) the required flow through the sidewall jets to achieve that rate and (3) the required flow through the pump jet nozzle to lift all fluids and cuttings to the surface. Mining rates of up to 1 cu yd per min have been achieved in mining sandstones, weathered limestones and laminated shales. In these instances, required flow through the sidewall jet nozzles averaged 400 gpm at 800 psi. Flow rates through the water courses of the rock bits averaged 100 gm at 800 psi. The required flow rate through the pump jet nozzle increases with the mining depth and must be properly adjusted to lift all fluid and cuttings to the surface as fast as they accumulate in the borehole. The fluid level in the borehole must be maintained below the sidewall jet streams at all times to achieve maximum mining rates. At a mining depth of 200 ft, a flow of approximately 500 gpm at 800 psi would be required through the pump jet nozzle to lift 1 cu yd of cuttings and 500 gal of mining fluid per min. The mechanical efficiency of jet pumps that have been used has averaged about 35%, which results in large hydraulic horsepower requirements. An air-lift pump

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has been used in conjunction with the jet pump to reduce the hydraulic horsepower requirements on deeper mining operations. Compressed air was supplied to the air-lift pump head through a third pipe passing down through the center of the pressure pipe. Calculations have shown that the combination system of the jet pump supplying the submergence head to the air-lift pump would be feasible for mining operations to depths of 1500 ft. Pressurization of the borehole with compressed air to reduce the lift horsepower requirements have been accomplished using a rotating packer to seal the annulus between the kelly and the well casing. Calculations indicate that the combination of the three lifting systems would be feasible for mining small cavities to 7500-ft. depths.

Tests Can Determine Mining Rates

Mining-rate estimates can be made from small-scale jetting tests and detailed mechanical-properties tests on cores of the formation. Where large representative samples of the formation are available from outcrops or conventional mining operations, full-scale jetting tests should be conducted. A large jetting test stand has been constructed to handle 2-ft cube samples of the formation and test the cutting rates to 30-ft radial distances. Jetting tests have been conducted on samples prepared from a 5:1 portland cement-sand mixture cured for seven days. Cutting rates of 6 cu yd per hr were achieved on these samples at a radial distance of 15 ft. Cutting-rate tests were also conducted on Selma chalk samples. Owing to the low permeability and closed-cell structure of the Selma chalk, several changes in mining techniques had to be implemented to achieve economical mining rates. These changes included raising the sidewall-jet-stream velocity from 325 to 400 fps and cutting the chalk into 6-in. slabs which could then be ground to $\frac{1}{8}$ -in. particles by the rock bit. It is estimated that mining rates of $\frac{1}{2}$ cu yd per min could be achieved with these techniques. Mining-rate tests have not yet been conducted with suspended abrasive particles in the jet streams because of the maintenance problems they would create in conventional high-pressure pumps. However, the recently developed Hydro-Torq explosion-type pump will allow the recirculation of abrasive particles without undue maintenance problems. The mining tool has been redesigned to permit the separation of the abrasive particles from the main fluid stream and to direct the flow of the particles into the center of the sidewall jet streams, and mining-rate tests are now being planned to evaluate this technique. Where sufficient abrasive particles of the proper size are not available in cuttings, steel shot in sizes up to $\frac{1}{4}$ in. in diam can be substituted. The steel shot can be recovered from the return cuttings for recirculation. Mining rates in hard, brittle formations should be substantially increased by this technique.

Various basic shapes of subsurface excavations that could be mined by this system are illustrated by Fig. 2. The circular disc cut with a flat roof and cone-shaped bottom would be used where the roof strength was adequate to prevent caving. The multi-

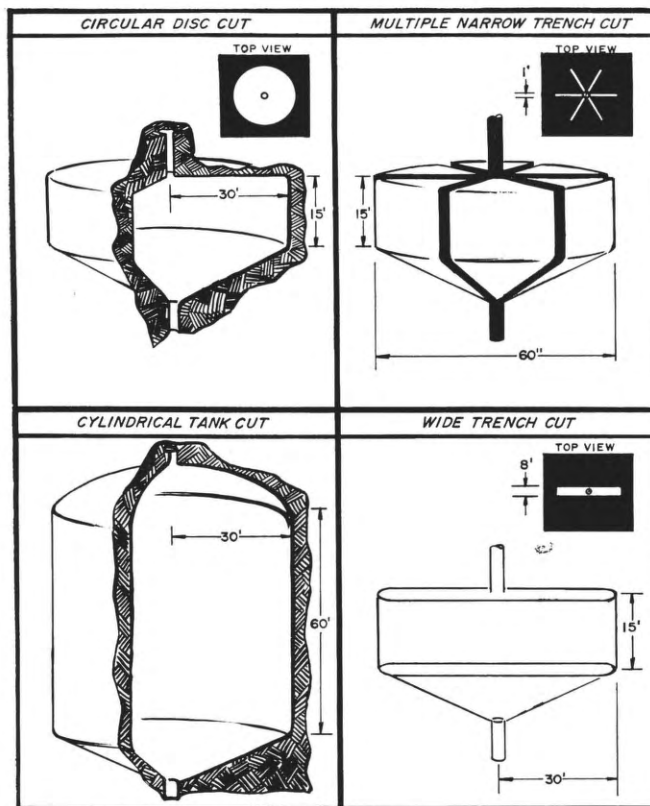


Fig. 2—Subsurface excavations that could be made with the borehole mining tool.

ple narrow trench cuts have been used to increase the production rates of oil and water wells. The cylindrical tank cut with a dome-shaped roof and conical bottom would be used for underground storage vessels. The wide trench cut would be used in mining a vein of ore. Combinations of these basic cuts can be employed with a high degree of accuracy. Vertical orientation of the sidewall jet streams can be controlled within approximately 2 in. Azimuth orientation can be controlled within approximately 1°.

Borehole mining of caverns and lateral trenches into the sidewalls of irrigation wells and one oil well has been the only field application of the process to date.

Promise in a New Pump

The Hydro-Torq explosion-type pumps were developed to provide a high-pressure pumping system with a minimum of moving parts that contacted the abrasive-laden fluids. This was accomplished by combining the engine and pump into one machine. The basic operational cycle of the system is illustrated in Fig. 3. Fluid enters through the suction valve, filling the pump cylinder to the desired level while the exhaust valve is being held in the open position. After the exhaust valve is closed, the fuel-air mixture is injected into the cylinder at the desired pressure. When the intake valve closes, the spark plug ignites the fuel-air mixture and the resulting explosion drives the fluid out through the discharge valve at high pressure. Opening of the exhaust valve releases the residual exhaust gas pressure from the cylinder through an air compress-

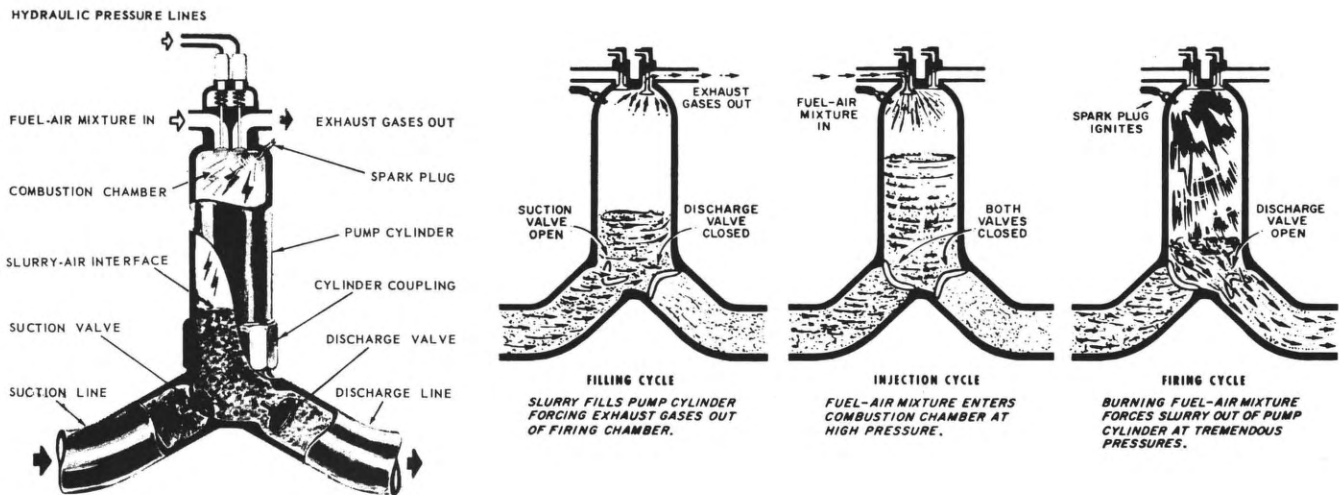


Fig. 3—Diagrams showing the Hydro-Torq explosion type pump (left) and its operation cycle.

sion system which is not illustrated, Hydro-Torq slurry pump units are comprised of six of these cylinders, each of which is a combination internal combustion engine and reciprocating pump. All six cylinders are coordinated to fire at equal intervals by the electrical and hydraulic systems which open and close the engine valves in proper sequence. Any individual cylinder can be shut down for complete repairs while the unit continues to pump with the remaining five cylinders firing at a slightly faster rate. Rate of firing and power per cycle can both be varied to control total displacement and discharge pressure. Liquid fuel injection or vapor fuel metering systems can be provided for the particular fuel to be burned. Floating pistons can be provided in the cylinders for maximum fuel efficiency and slurry displacement as needed. Slurry concentrations of up to 60% by weight have been pumped with negligible wear and no appreciable degradation of the slurry. It is anticipated that this pumping system will be used to power the mining tool and circulate abrasive particles through the sidewall jet streams at the same time. There are also plans to use the system for long-distance piping of mineral ore slurries from subsurface hydraulic or conventional mining operations, an application which would offer substantial savings in transportation.

Mining Methods and Advantages

Mining operations would be initiated by excavating the cone-shaped sump in the underlying formation to facilitate the return of the cuttings and fluids to the jet eductor suction. Excavation of a dome-shaped cavity above the mineralized zone might be necessary to prevent caving of the overburden and dilution of the ore in some formations. Following these preparatory cuts, hydraulic mining of the mineralized zone would be initiated. Progressive cylindrical cuts would follow until the desired radial mining distance had been achieved. Borehole spacing could be designed to leave pillars between adjacent boreholes to support the overburden. The pillars could be mined out using additional boreholes drilled through the center of each pillar. Longwall mining methods could be approxi-

mated with a progression of square-cut mining patterns allowing the overburden to cave behind the mined-out area.

Mining of subsurface mineral deposits will require detailed exploration work to define the orebody, an evaluation of the borehole drilling costs and estimates of the optimum mining rates and costs. Definition of the orebody should include the value per ton, thickness, areal extent, dip, strength of the overburden, permeability, porosity, hardness index, compressive strength, fluid production estimates if saturated, and the character of the underlying strata. Lenticular deposits that are more than 6 ft thick would be the most amenable to this system of mining. Approximately 220 tons of formation can be mined for each foot of thickness with a 60-ft-diam circular mining pattern. Borehole-drilling cost estimates should include the cost of drilling the borehole to a depth of 20 ft below the mineralized zone, setting casing down to the top of the mineralized zone and pulling the casing after the mining operations are completed.

Borehole mining offers several important advantages over conventional mining under favorable geological conditions. Immediate production of the highest-grade ore would substantially reduce initial capital requirements. High rates of production could be achieved with a minimum of labor and equipment. Small isolated orebodies could be mined without a material increase in mining costs. Many underground mining hazards would be eliminated, allowing the development of unstable, gaseous, or water-saturated deposits. Crushing and grinding costs would be substantially lowered with some formations being reduced almost to grain size by the jet streams. Slurries from the borehole mining operations would be an ideal feed for on-site hydrometallurgical milling operations. Tailings from the milling operations could be pumped back into the mined-out caverns to control subsidence and reduce the waste-disposal problems. Over-all mining and milling costs could be very competitive with conventional methods under favorable conditions, allowing the development of some presently subeconomic mineral deposits. NE