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Geotechnology - A Solution for Unconventional Uranium

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Abstract:

Its significant depth, thin mining interval and low ore permeability made the Aqtau sedimentary uranium deposit a mining challenge. Nevertheless, the growing demand for uranium in the former Soviet Union forced construction of a gargantuan (3km edge-to-edge) open pit. Strip-mining commenced at the shallowest (40m) flank of the ore body. Over the years, the deepening ore layer pushed the strip-ratio higher and higher and about a quarter of a century later, the overburden (caprock) thickness had reached 80m while the ore body "shrunk" to 0.8m, bringing the stripping ratio to 100.The engineers knew that one day the open pit economics would go below the break-even point and all operations would have to cease. It was calculated that some 40% of the entire ore reserves would be extracted by that time and the question "*Then what?*" remained on the agenda from day one.

About 10 years into production, a then-relatively-new geotechnological methodBorehole Mining(BHM) [1] came into consideration. If feasible, it could be used to continue operations for the remaining 60% of the reserves and extend the mine life for an additional 18-20 years. That break-even day was projected to occur in the 1980s. This lead time gave the scientists and engineers plenty of opportunity to investigate the feasibility of BHM, develop the technology and then maximize its potential. R&D, lab tests and field trials were begun in the early 70s, and by the late 80s, BHM had reached a pilot-commercial production stage while the strip mine continued its conventional operations.

The Chernobyl disaster, the resulting plunge of uranium prices and disintegration of Soviet Union forced the closure of the entire mine in the early 1990s right when the technology reached a new level: application of a second geotechnological mining method - a post-BHM in-situ leaching (ISL) [2] phase which was seen to have the potential to increase future uranium extraction from 60-65% (BHM) to 85-90% (BHM+ISL). While this second phase of geotechnological phase was not initiated, this project became and remains today the longest-lasting and most commercially successful application of borehole mining in the world. Below, the combined BHM+ISL technology is described in detail.

Keywords —**Borehole mining, in-situ leaching, geotechnology, remote operated, combined technology**

I. INTRODUCTION

Located near the East coast of Caspian Sea, some 20km from the city of Aqtau (then Shevchenko), the Melovoye uranium deposit was discovered in 1956 and production commenced in 1964 [3]. The approximately 1m thick ore body slowly dips E-W at less than 1^{o}. The ore, cap- and bedrock are represented mostly by claystone with slightly varying physical properties and colors. Both the cap- and bedrock have a filtration rate of less than 0.01m/day which makes them almost impermeable natural barriers to ISL reagents. At the same time, the ore layer permeability is not much greater than that of the hosting strata. It is less than 0.1m/d which negated the commercial application of the standard ISL method at Melovoye. Underground mining was also rejected due to a number of reasons including: thin ore, low caprock stability, radiation and other hazards.

All the above issues led the engineers to proceed with apparently the only applicable post-strip-mine technology - borehole mining. It was also realized, that extraction of ore would result in creation of underground voids (stopes) and pillars which would make BHM operations similar to underground room-and-pillar technology. But most importantly, these voids would technically increase permeability of the overall ore zone. Thus, ISL was back in the picture as a post-BHM means of continuing extraction of uranium from the remaining pillars.

II. COMBINED BHM AND ISL TECHNOLOGIES OVERVIEW

One of the most important parameters of BHM is the cutting radius which defines the size of the stope and the distance between the boreholes. A 273mm (10-3/4") BHM tool equipped with a retractable 0.5m-long hydromonitor (Fig 1a) was developed and was capable of cutting ore at a 9-10m radius.

Fig 1. a - 273mm BHM tool retractable hydro-monitor; b - 168mm BHM tool (pressure test)

The other important parameter of BHM is the critical span between two pillars beyond which the roof collapses. Field tests indicated that the critical span for Aqtau claystone would be about 8-10m. Thus, an18-20m diameter cylindrical stope could not be cut without additional support. That factor forced a change in the ore cutting pattern from circular to sectoral (Fig 2).

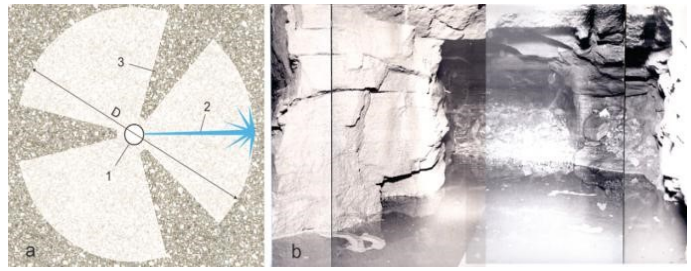

Fig 2. BHM stope with 3 sectoral pillars; a - drawing (plan view): 1 - BHM tool, 2 - water jet, 3 - roof supporting pillar, D - diameter of the stope; b - stope photo taken thru a borehole (all photos taken in late 1980s)

To allow withdrawal of a retractable hydromonitor, a borehole must be under-reamed to 1.5-2 m. For this purpose, an additional, 186mm (6-5/8") OD BHM tool with built-in hydromonitor was designed (Fig 1, b). Based on the sectoral concept and specifically for Melovoye, a BHM rhomboidal room and pillar BHM system was developed forming a series of Mercedes-star pillars, presented in fig 3.

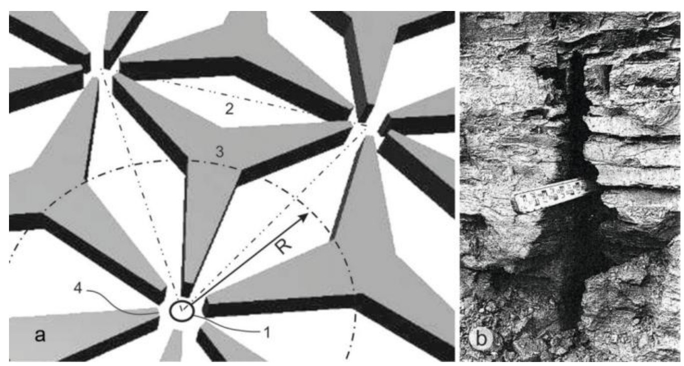

Fig 3. Carving the ore: a - boreholes (1) drilled in triangular pattern, rhomboidal stopes (2), roof supporting pillars (3) and underreamed chamber(4). R - water jet cutting radius;b - approx. 3m deep vertical slot water-jetted across the ore layer

Rhomboidal stope geometry was chosen in order to create pillars of a size sufficient to ensure stability of the stope for the duration of working-out of a particular stope. Two BHM tools were used simultaneously from opposite sides to cut each stope. Following completion of the stoping process, rock pressure forced the roof to collapse and the pillars to crush. The far area in Fig 2b (center) illustrates an initial collapse in the worked-out stope. This roof-supporting technique received the name *Borehole mining controllable collapse and subsidence*. Changing the geometrical parameters of stopes and pillars allowed control of roof stability, ie. to delay or accelerate roof collapse. After roof failure and pillar crushing, the remaining pillars were ready for the sequential ISL.

III. POST-BHM ISL

Preliminary modeling of post-BHM ISL indicated that the reagent would migrate mostly through the collapsed voids rather than through the pillars, especially those which had been only partially crushed, and so uranium extraction would not reach the maximum possible rates. To force more reagent through the pillars, special ISL boreholes were drilled into the center of each star-pillar and three vertical slots were cut along the central plane of each arm of a star. In Fig. 3b a vertical slot cut through the ore at the BHM experimental site is shown. A 168mm BHM tool was used to underream BHM wells and to cut vertical slots. The BHM voids, ISL slots and leaching pattern are presented in the Fig 4.

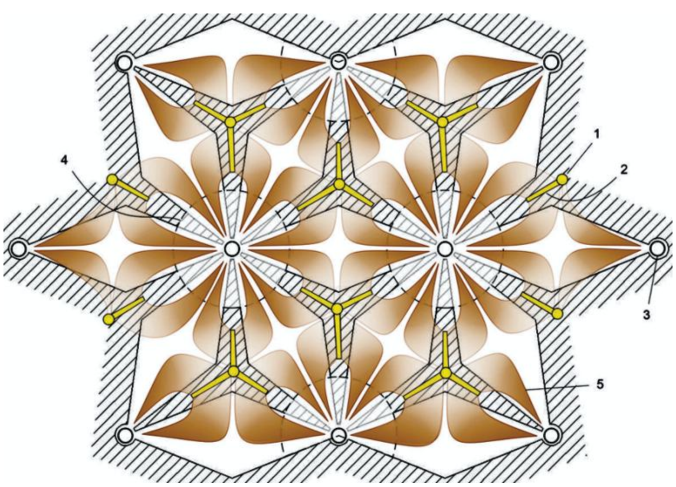

Fig 4. ISL from BHM pillars

1 - injection well, 2 - vertical slot, 3 - production well, 4 - initial pillars crash zone, 5 - solution flow

Two main reagent flow patterns were used: (1) through the slots into the voids (Fig 4) and (2) reverse. Additionally, sequential opening and closing of certain ISL wells allowed redirection of the reagent flow in the most preferred pattern. The overall contour in Fig 4 presents a single ISL block. The configuration and size of such a block was dependent on specific ore conditions and varied within a wide range - from as little as 3 stopes to a few dozen.

IV. QUICK-PACE BHM OPERATIONS

Obviously, rock pressure works non-stop, 24/7. If for any reason (ie. emergency) the cutting process must be stopped even for a few hours, it is very possible that unfinished stopes would start to cave-in and complicate mining finalization at that particular location. The geometrical parameters of the stopes and pillars were chosen such that they allowed finalization of borehole mining in each stope just before it began to collapse. Therefore, all BHM operations needed to be executed in a continuous manner. This technique allowed formation of the maximum-possible size of BHM stopes and extend the distance between the boreholes to the limits. In other words, BHM, in this case, was a dynamic technology which required avoidance of unnecessary breaks. Because of that, the working shift schedule was altered to three eight-hour shifts forming a 24/7 non-stop BHM operation cycle. In Fig 5, the BHM stope is shown.

Fig 5. A fragment of the BHM stope panorama

1 - 273mm BHM tool, 2 - pillar, 3 - caved roof fragments, 4 - survey ruler lowered thru a control hole

The stope in the Fig 5 is completely worked-out and the roof has already begun to collapse. This is the time to remove the tool and make all the preparations for ISL (the BHM tool is left in the void exclusively for taking this panorama). Within the next 24-36 hours, the void will be filledto some 60-75% with caprock and pillar material. That would be the time to commence ISL operations which are significantly slower than BHM and take months. During this time, the remaining pillars will crush more completely and the stopes will be filled to some 85-90% which will enhance reagent and solution migration from injection to production areas.

V. SUBSIDENCE

As the BHM void's roof begins to collapse, the overlying caprock starts to cave-in layer by layer creating a collapsing (moving) zone [4] whichgrows upward until it reaches the surface, where subsidence (Fig 6)occurs.

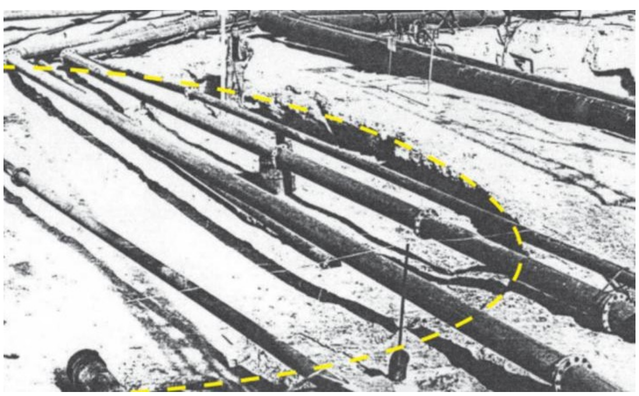

Fig 6. Circular subsidence (contour highlighted)

The subsidence in Fig 6 (BHM depth - 60m) occurred slightly over one year after all the operations in this block were completed. As caving material swells some 10-15%, the subsidence happened rather smoothly within approximately 2-3 weeks after which it stopped and was measured as 0.3m at the deepest point. It is possible that over the years the collapsed material will consolidate more and the final depth may reach 0.5-0.6m.

The subsidence occurred directly above the experimental circular stope, similar to that presented in Fig 2. Its diameter "shrunk" about 15%. As the depth of BHM progressed to 90m and the stope-pillar pattern was changed from 3 pillars (surrounding each BHM well) to 6, subsidence stopped completely (at least for the following 3-5 years of observation).

During the late 80s, many nuances of the technology were improved, adjusted and polished. The main commercial borehole mining parameters were as follows:

- Total estimated uranium reserves - 43'800t*
- Ore SG approx. - 2
- Uranium concentration in the ore - .03-.05%
- Final mining depth - over 80m
- Ore layer thickness, approx. - 0.8m
- Ground water table - 6m below the ore body
- BHM wells pattern - triangle, 18 x 18 x 18m
- Water jet volume and pressure - $200m^3/h$ @ 75atm
- Slurry consistency(by volume), average - 10-16%, spiking to 25%
- Ore production rate(per tool), average: 20-32 m^3/h; max. - up to $50m^3/h$
- Total BHM tools working simultaneously - 6
- Resources developed by conventional mining - planned 40%, real - 60%

- Final BHM portion of the total mine production - 10% (90% by stripping)**

* Reference: 1tU = 1000t of coal = 40M KWt of electric power [5]

** BHM/ISL operations were planned to replace all strip mining within the next 8-10 years.

Major BHM/ISL technologies steps, their sequence and approximate duration presented in Table 1.

TABLE 1. Major BHM and ISL operations timeline(as example, per block of 15 stopes shown in Fig. 4)

	BHM+ISL main stages	Months					
		1	2	3	4	5	6
1	Drilling/casing of BHM & ISL wells						
2	Borehole Mining						
3	Transition to ISL						
4	Time offset to crush pillars*						
5	In-situ leaching						
6	Casing removal for reuse						
7	Wells liquidation						

* - if necessary, offset time can be extended

VI. RIGLESS BOREHOLE MINING

To cut a rhomboidal stope, the tool had to be rotated back and force (pipe connections were modified to prevent the column from being unscrewed) within a certain angle (approx. 42^0) and moved up and down within the ore body. That process became a tedious task for a drill rig operator as typical rigs are designed to constantly rotate a drill string. Then, a few years before mine closure, this project achieved yet another milestone - rigless BHM operations. Custom-built, skid-based, hydraulically operated, PLC-programmable "robots" (Fig 7)controlled waterjet cutting by slowly shifting the tool up and down and rotating it left and right.

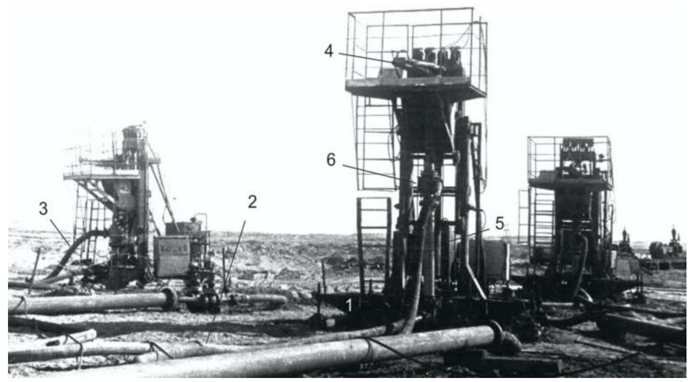

Fig 7. BHM tool operating towers

1 - skid, 2 - HP water hose, 3 - slurry hose, 4 and 5 - horizontal and vertical hydraulic cylinders, 6 - swivel

The cost for "robots" was less than 50% of that for standard drill rigs and personnel requirements were reduced by a factor of 3. These efficiencies allowed the "robots" to completely replace standard drill rigs at BHM operations. And, thanks to automation, the accuracy of the stope and pillar geometry was improved measurably.After a stope was worked-out, each tower was repositioned to the next well, water and slurry lines extended and BHM operations resumed. In Fig 6, those extended pipelines are hovering over the subsidence. At this point, all the BHM personnel, equipment and operations were moved further forward, away from the danger of earth surface subsidence.

It is important to note that Aqtau claystone is a relatively strong material. It possibly defines the upper boundary for application of borehole mining. This means that softer, more unconsolidated ores such as sand, sandstone, softer clay (kaolin), young coal (lignite) and similar resources, are more appropriate for borehole mining and thus mining rates would be much higher than BHM at Melovoye. Nevertheless, the Aqtau project exceeded all the expectations and left the door wide open for mine revival.

Conclusion

Although initiated as a conventional mine, Melovoye was supposed to transition into a sophisticated unconventional mining showcase. Two geotechnological methodsBHM and ISL were designed and implemented to change the game twice. Unfortunately, it happened only partially. Today, only the abandoned gigantic pit and ugly waste tailings are left to remind us of the previous mining activities. Desert winds pick up contaminated dust and blow it kilometers away to the distress of Aqtau city residents. It has been over a quarter of a century since the last truckload of ore left the mine. The USSR has broken up and vanished. But the ore is still there and modern mining technology has been commercially tested and is now available.

BHM and ISL require no earth to be moved. No ore need be exposed to the miners or atmosphere. From its natural location, uranium can enter a pipeline and see the light for the first time only after arrival at the processing plant. In fact, BHM+ISL will not require miners whatsoever. Instead, process engineers will monitor and control the mining operations from the ease of air-conditioned control rooms. It is mining without miners and is available to be implanted today.

Acknowledgement

For over two decades, the Aqtau BHM site was an experimental playground and launchpad for countless R&D, ideas, techniques, inventions, publications, etc. They shaped early borehole mining concept and transformed it from lab-prototypes to a commercial technology. The success of the Melovoye BHM project was a result of cooperation of many talented scientists, engineers and specialists from Russia and Kazakhstan. Their contribution streamlined the road to success for many borehole mining projects worldwide. The author acknowledges their valuable contributions.

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