A REPORT TO

PETROLEUM TECHNOLOGY ALLIANCE CANADA

A Preliminary Review of
Underground Mining of Currently Inaccessible Hydrocarbon Resources

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This report presents the results of a review of underground mining methods for currently inaccessible hydrocarbons. A framing document was provided by email on February 7, 2006. A brief meeting was held with T.R. Heidrick on February 15, 2006. The focus was clarified to be novel ideas for mining 25 years in the future. The work effort was limited to two days of work and a brief report was requested for February 28, 2006.

Clayton V. Deutsch directed the work. Brainstorming and scoping was conducted with a small group of mining engineers. Jeff Boisvert prepared a summary document based on the brainstorming session. The summary document was revised, edited, formatted and submitted on time and (barely) within budget.

Respectfully Submitted,

Clayton V. Deutsch and Jeff Boisvert

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Abstract

Significant hydrocarbon resources in Alberta are inaccessible using current methods. Oil sands located at depths greater than surface mining can access may be exploited using insitu technology; however, about 24% of the reserves in the oil sands are uncontained and cannot be extracted with insitu technology (PTAC, 2006). Moreover, 26% of the reserves in the McMurray formation are located in a carbonate formation and have proven to be difficult to produce because of low initial permeability (PTAC, 2006). One solution that could be applied to both of these significant sources of reserves would be to utilize underground mining techniques. Traditional methods, such as longwall mining, hold promise but may be difficult to implement because of ground control issues. Other proven underground methods such as hydraulic jetting and caving may be able to take advantage of the geotechnical weakness of the oil sands. Finally, some alternative methods that have not yet been explored in the realm of mining are considered as possible areas of future research.

Traditional Mining Methods

Longwall Mining

Longwall mining could be used to extract currently inaccessible oil sands. The lateral extent of oil sands deposits make longwall mining an obvious choice. Mining would progress with long, thin slices being seared off the active face while advancing gradually along strike. The roof above a panel is supported temporarily while mining is occurring and the roof is allowed to cave in once the panel is complete. The major difficulty in implementing this method would be the geotechnical issues related to roof instability. While mining a panel the roof must be temporarily supported to protect equipment and personnel and it is anticipated that the high concentration of sands in the oil sand deposits would pose significant geotechnical difficulties while attempting to support the roof. If roof stability issues can be resolved, longwall mining has proven to be an economical underground mining method when extracting large volumes of ore. To assist in determining the feasibility of using longwall mining in the oil sands the following statistics provide the range of dimensions of longwall mines in the U.S (Hartman and Mutmansky, 2002).

Dimension	Lower Range (m)	Upper Range (m)	Average (m)
Panel width	182	365	269
Panel length	911	4450	2615
Panel height	1.2	7	
Depth of cut	0.76	1.1	
Overburden Depth	61	823	

Another significant challenge with longwall mining is the panel height. The upper range of current technology is about 7m; however, the oil sands deposits are significantly thicker than this. It is unclear if or how longwall mining could be applied in multiple passes.

Continuous Miner

A continuous miner could be used, based from the surface and extending into the highwall or based from an underground drift. This machine would advance through the deposit while supporting the roof. When the miner is withdrawn the roof can be allowed to fail or tailings could be pumped into the opening to support the roof and be used as back pressure to help withdraw the continuous miner and increase pore pressure. A drum type continuous miner is shown in Figure 1. As with longwall mining the stability of the roof would be the major issue with this technique as it must be supported while mining is taking place. One advantage of both longwall and continuous mining is that the roof is only supported temporarily which can often be achieved in areas where long-term support is not feasible. Some ideas for overcoming roof support problems are presented below.

Block Caving

This would involve developing drifts below the deposit and drawing out material from these drifts. As the oil sand is drawn out the surrounding material is aloud to cave in behind the extracted ore. This provides a continuous supply of material at the mining face, depending on the geometry of the deposit, its thickness, the angle of repose of the material and the tendency of the material to cave (see Figure 2). Because caving requires a weak roof, the geotechnical instability of the oil sands is an advantage. Some factors to consider that would make this method feasible include:

1. Deposit dip – the deposit must have a significant dip to allow the production opening to be constantly replenished by caving. If the deposit was flat, it would be difficult to keep material flowing to the production drift.
2. Thickness of the deposit – the deposit must be large enough to minimize the influence of dilution. As oil sand is withdrawn the host rock may cave into the production drift causing excess dilution and would be an issue if the surrounding host rock is weak.
3. Angle of repose – if the angle of repose of the material is close to the dip of the deposit, material would be constantly flowing down from the deposit to the production drift (see Figure 2).
4. The tendency of the material to cave – getting the material to cave into the production opening can often be a problem, but this should be easily accomplished with an oil sands type material. This can be assisted by blasting if necessary.

The acceptable levels of dilution and the geometry of the deposit will determine the feasibility of using block caving. One idea to reduce the dilution would be to freeze the surrounding material so that it would remain intact while the oil sands cave into the production openings, as is done in Saskatchewan potash mines.

Hydraulic Jetting

Hydraulic jetting is traditionally used to mine placer type deposits but could be applied to oil sands because of the geotechnically weak ore. The premise would be to fire high pressure water at the oil sand causing it to wash down or cave into a collection area where it could be piped to processing. This would have the added benefit of putting the oil sand into a slurry form underground, allowing it to be piped to the surface. Roof support would be necessary to protect personnel and equipment underground but the oil sand could be exploited from a distance, keeping the equipment and personal out of the areas that are being encouraged to cave (see Figure 3). The feasibility of using hydraulic jetting would depend on the strength of the oil sands and its reaction to a high pressure stream of water.

Hybrid Drainage

Developing drifts under the deposit would allow drainage points for oil extraction. Fan drilling would allow access to the deposit and provide conduits for steam injection or blasting. Rather than collecting the ore as it caves, as in block caving, the deposit could be drilled from below and injected with steam or blasted. Oil would then be extracted through these drill holes, or if blasting is utilized, the holes would have to be re-drilled to extract the ore (see Figure 4). This would be beneficial in the carbonate setting where the problem of low initial permeability could be solved by blasting or circumvented because of the high density of drill holes used to produce oil. A major benefit of this method is that all drifts could be placed in the host rock which should be stronger than the oil sands. Access to the oil is achieved through drilling the deposit from these geotechnically stable areas, minimizing ground control issues.

Auger Mining

Once the stripping ratio makes surface mining uneconomical, augering could be used to extract additional oil sands from the bottom of the open pit. An auger is used, beginning from the bottom of the surface mine and is operated remotely from the surface to extract oils sands below the highwall.

A modification of this method would be to extend its use to an underground setting. Augers could be used from drifts in an underground mine to draw material down into the production opening. It would be anticipated that as material is augered more material above would cave onto the auger steel. This provides additional breakage in the surrounding oil sands which could increase the productivity of other insitu surface methods (see Figure 5). This would be ideal for the carbonate deposits where initial permeability would be increased by the fracturing. This fracturing of the oil sands could also be exploited by pumping steam into the deposit and draining the oil through pipes underground rather than from the surface. This method also requires less roof support as access can be created in the host rock; however, it may be difficult to achieve the levels of production necessary for economical oil sands production.

Inclined Room and Pillar

This method is common with shallow dipping or horizontal deposits. The technique extracts the ore using conventional mining equipment such as LHD's, front end loaders, mine cars, etc. but leaves behind pillars of ore to support the advancing face. This would be a very difficult technique to implement in an oil sands setting because the roof must be supported for a long period of time. Ideas for increasing roof support are listed below, but it is anticipated that methods requiring temporary roof support or no support at all would be preferable to room and pillar mining.

Increasing roof support

All methods mentioned thus far have required some type of roof support. The ability of oil sands to support the roof is questionable and, most likely, would have to be assisted with artificial supports. This could be done by freezing the oil sand to provide support as in room and pillar mining or block caving. Another option to help support the roof would be to develop a cementing agent that would allow tailings to be used as synthetic supports. There is an abundant quaintly of sand available in mining oil sands and it would be convenient to use this sand in a cement mixture to help provide support for underground mining operations. Moreover, hydraulic supports can be used for temporary support where necessary.

Borehole Mining

Similar to currently implemented insitu technology, borehole mining would necessitate drilling a well into the deposit. The major difference would be that instead of drawing up oil, oil sands would be drawn up using a recirculation fluid. This fluid would be pumped down the well and as it is drawn back up it would carry with it oil sands. As the oil sand is drawn from the well more would cave into the well and the cycle would repeat. The major drawback expected for this type of mining would be the expense of drilling a well with limited production potential. The deposit would have to be significantly thick to continuously supply the well with oil sands. Moreover, the cost of pumping oil sands up a well would be significantly larger than the cost of current insitu technology where only the oil is pumped. A final restriction on this method would be its predicted ineffectiveness in the carbonate areas. The deposit would have to be sufficiently weak to cave as material is drawn out from the well and the carbonates may not do this.

Techniques Requiring Further Research

Underground Bucket Wheel

Oil sand mining requires a method capable of extracting high volumes of material. A simplified bucket wheel could be used underground to extract the high volumes of material necessary to make oil sands mining profitable. Two drifts would be driven parallel to the strike of the deposit and a string of buckets would be attached between them. This string would be pulled back along strike and the ore transported though the drifts. The roof would be allowed to cave behind the string of buckets as in longwall mining. If the deposit is thick, this could be repeated multiple times as the deposit is undercut and caves to fill the void created by the first pass. This would also fracture the remaining oil sands to increase the effectiveness of other steam injection/drainage techniques. Figure 6 shows this technique. Further research and development would be required to design the necessary equipment to transfer this surface mining technique to an underground setting.

Minimization of Mining

The benefit of scale has been known for years, but only recently has miniaturization become attractive. Using multiple small but cheap continuous miners may be economical. Taking this concept further, into the area of nanotechnology, would see thousands or even millions of extremely cheap nanites that may even be powered by the oil sands they would be ‘living in’. They could tunnel and fracture the carbonate deposit to the point where conventional insitu techniques are feasible. These nanites could also send up information about the deposit to aid in reserve estimation.

Remote Underground Drainage

A small continuous miner or tunnel boring machine could be developed that would drill into the formation from a drift. This device would drag behind it a length of pipe, into which steam could be injected to increase the viscosity of the oil. Oil would then be drained through this pipe. The density of these drainage pipes could be controlled as necessary to achieve maximum profit. This technique would face similar difficulties as current insitu methods; however, it would have the benefit that multiple drainage pipes could be placed in one area to increase recovery, reducing the problem of low initial permeability. It could also be used as a hybrid method with one of the other techniques that would fracture the surrounding rock such as auger mining, blasting, undercutting with a bucket wheel, nanites, etc.

Bioleaching

Currently bioleaching is being used to extract low grade metals but it may be beneficial to look into the feasibility of using bioleaching for oil sand deposits. Bioleaching involves injecting bacteria into the deposit which alter the chemical makeup of the material. Perhaps there are some bacteria that could be injected into an oil sands deposit that could increase recovery and make some of the aforementioned methods more successful.

Gasification of Oil

Currently coal can be gasified and then used as a fuel source. It may be possible to gasify the oil sands underground and simply pump to surface.

Supplementary Ideas

Blasting

Blasting could be utilized to assist many methods mentioned in this report. Possible applications of blasting include: increasing the degree of fracturing which would be critical for auger mining, remote underground drainage, block caving and hydraulic jetting; increasing the temperature of the oil sands to increase productivity; and increasing the pore pressure of the oil sands which would benefit any drainage technique.

Remote Mining

Due to the geotechnical instability of oil sand material, ground control will be a serious concern with any underground method. The use of remote mining equipment should be seriously considered. This would allow underground mining to be conducted under more unstable circumstances as the danger to personnel would be minimized. There has been extensive work in the area of equipment automation and this may be a good application for this work.

Increasing Viscosity of Oil

As mentioned previously, if blasting is necessary it may also increase the viscosity of the oil sands. Some other ideas for increasing viscosity include:

1. Geothermal heating – drilling deep wells that draw heat from a geothermal source could become an inexpensive method of heating oil sands, but may have already been shown to be infeasible (PTAC, 2006).
2. Combustion of a small amount of oil sands underground – controlled purposeful ignition of oil sands underground could increase viscosity. Even if 5% of the oil is burnt underground the impact on recovery would most likely outweigh the lost oil reserves. It may be necessary to pump oxygen into the ignition areas as the oxygen supply underground is limited. Moreover, exhausting the fumes would be a necessity.
3. Using sonic, microwave or light waves to heat the oil may prove useful but would require further research.

Back Filling With Tailings

Underground mining often leaves behind a void, so long as the roof is not aloud to cave. This void could become a location for tailings disposal, which may have the added benefit of increasing the pore pressure in the oil sands that are left behind.

Conclusions

Underground mining could prove to be an effective method to extract oil sands located in carbonate deposits that give poor insitu performance or oil sands that lack the critical level of confinement necessary for insitu extraction. Some of the more appealing methods that have proven successful in other similar deposits include longwall mining, block caving and hydraulic jetting. The main advantage of these methods is that the instability of the oil sands would be a benefit rather than a roof support issue; however, these methods often require temporary support and providing this may even be difficult.

Auger and continuous mining seem feasible but may be limited by the high production requirement of oil sands mining. Production could be increased by pairing these methods with a drainage scheme that would see initial mining followed up with steam injection to drain the remaining oil. Moreover, this could be applied to the carbonate deposits to increase initial permeability.

Novel, but unproven, methods also hold promise. The recent advances in nanotechnology will alter the way industry approaches most problems, but is still a relatively young technology and is too underdeveloped to be applied now; however, in the future it could prove useful. Gasification is being applied to coal seams and could also be applied in an oil sands setting, but requires research into developing the idea. Applying a bucket wheel technique to an underground setting would also require some research and development and holds promise as a highly productive method.

All underground mining methods require some roof support and underground mining in the oil sands will require artificial support. This could be accomplished by using tailings sand with a cementing agent or by using more traditional hydraulic supports. An extension of this is the application of remote mining which would increase the acceptable level of risk as personnel would be removed from dangerous areas.

Figures

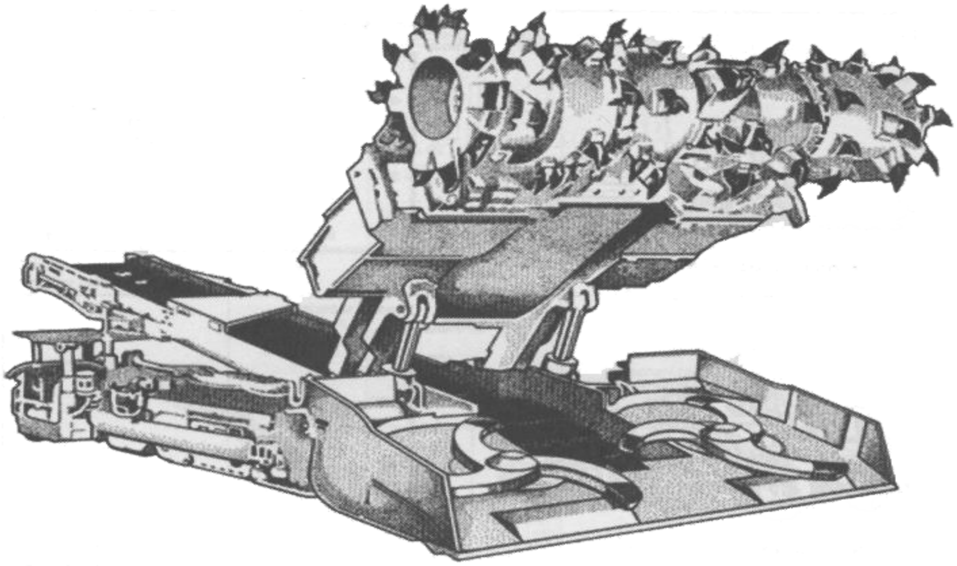


Figure 1: Drum type continuous miner (Hartman and Mutmansky, 2002)

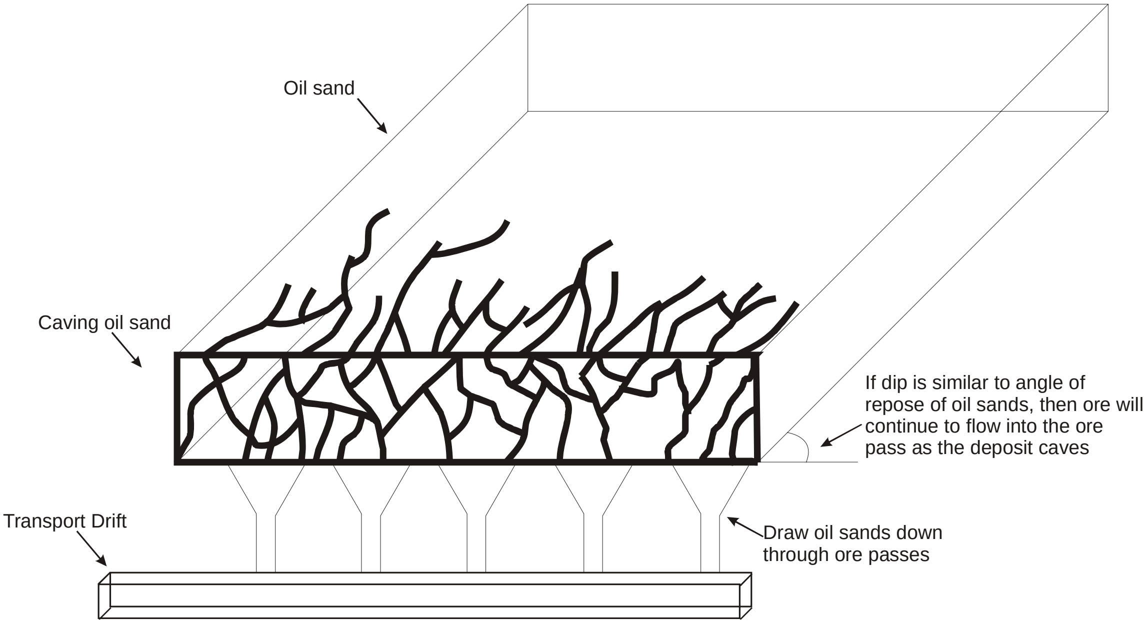


Figure 2: Block caving

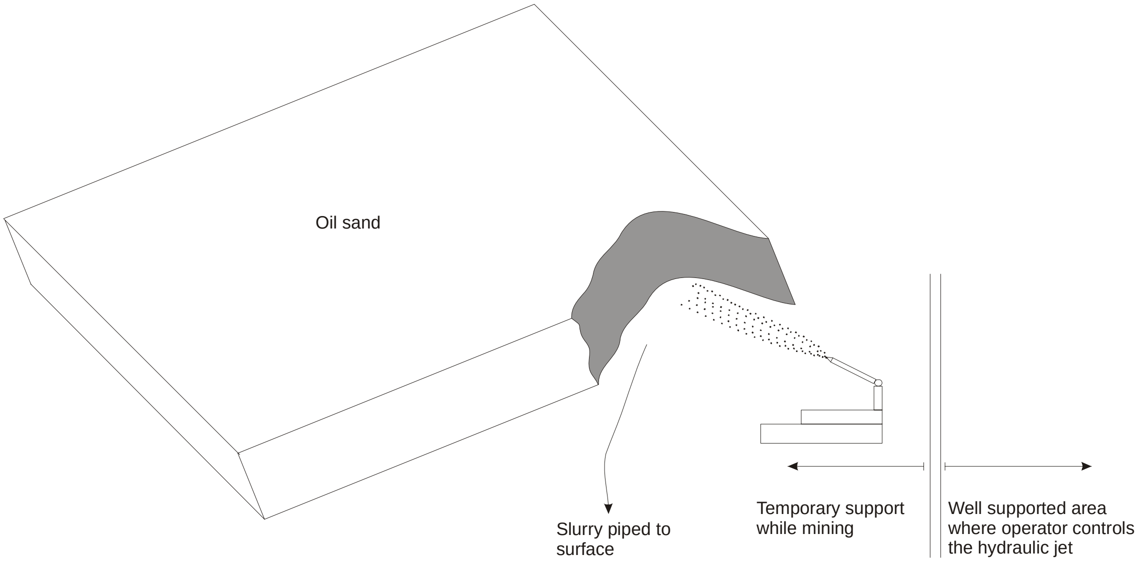


Figure 3: Using hydraulic jets to slurry oil sands.

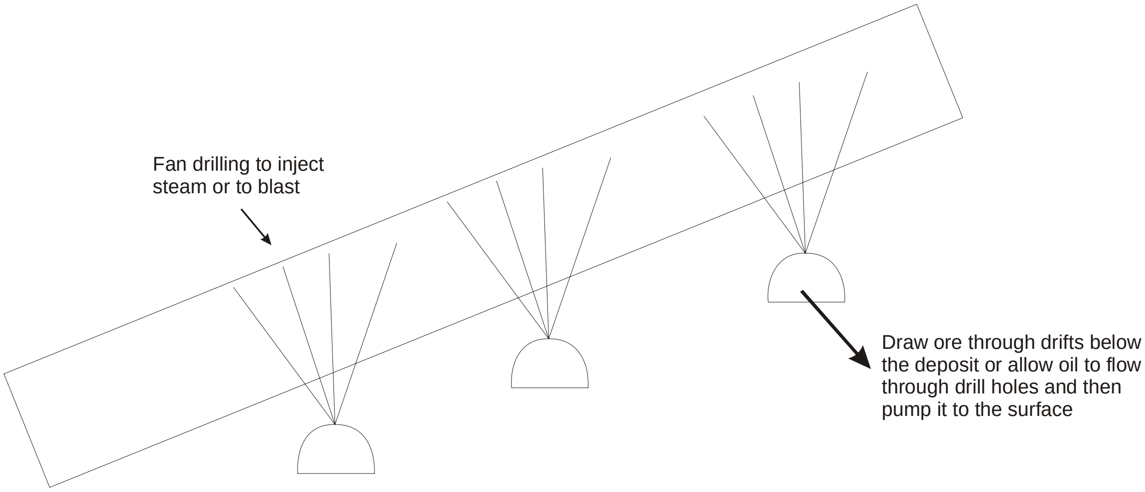


Figure 4: Cross section of oil drainage scheme

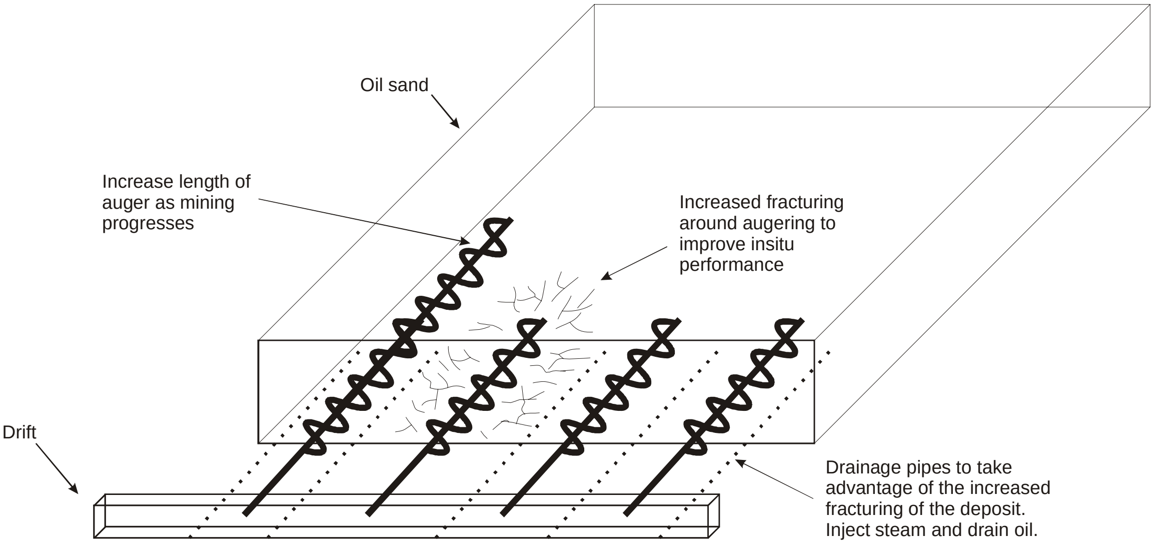


Figure 5: Modified underground auger mining

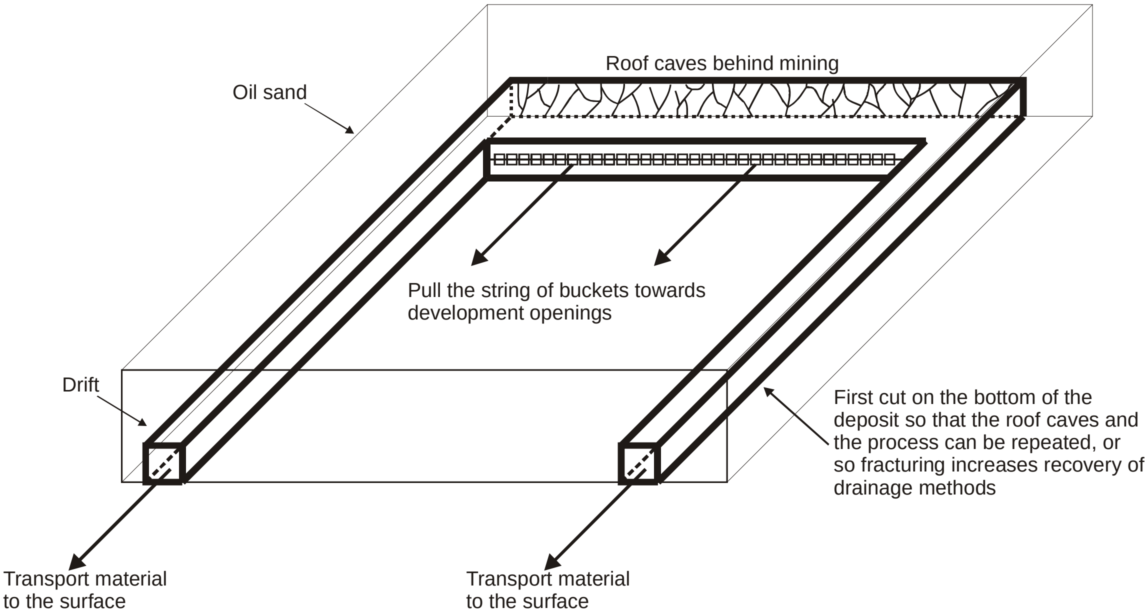
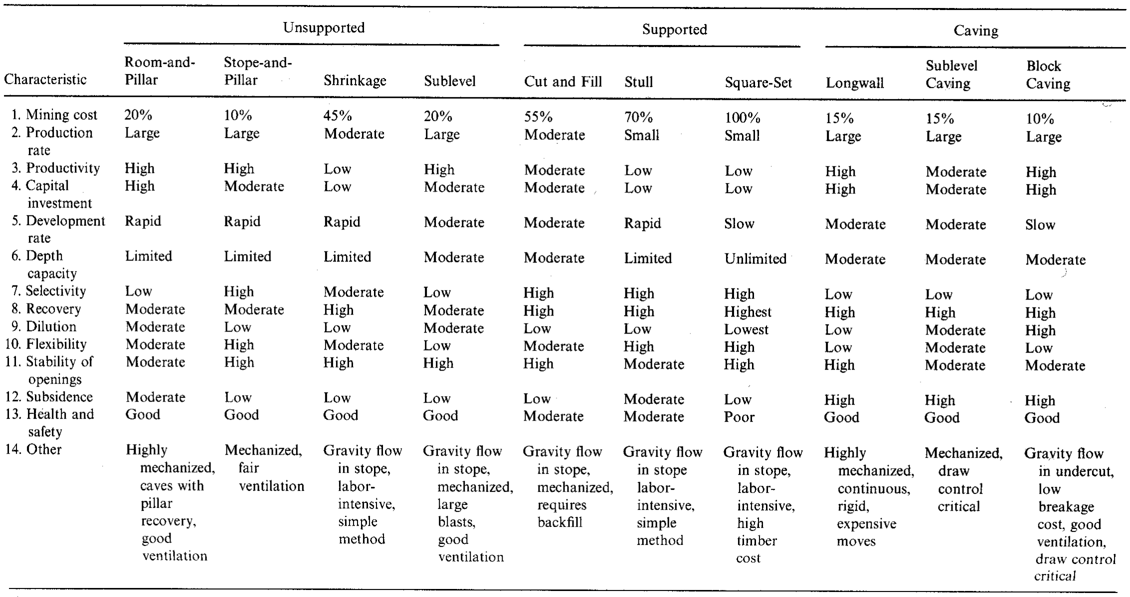


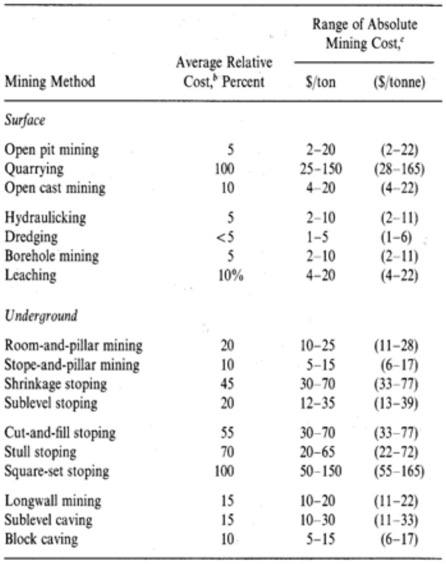
Figure 6: Underground bucket wheel mining

Table 1: The pros and cons of underground mining methods (Hartman and Mutmansky, 2002).



	Unsupported				Supported			Caving		
Characteristic	Room-and-Pillar	Stope-and-Pillar	Shrinkage	Sublevel	Cut and Fill	Stull	Square-Set	Longwall	Sublevel Caving	Block Caving
1. Mining cost	20%	10%	45%	20%	55%	70%	100%	15%	15%	10%
2. Production rate	Large	Large	Moderate	Large	Moderate	Small	Small	Large	Large	Large
3. Productivity	High	High	Low	High	Moderate	Low	Low	High	Moderate	High
4. Capital investment	High	Moderate	Low	Moderate	Moderate	Low	Low	High	Moderate	High
5. Development rate	Rapid	Rapid	Rapid	Moderate	Moderate	Rapid	Slow	Moderate	Moderate	Slow
6. Depth capacity	Limited	Limited	Limited	Moderate	Moderate	Limited	Unlimited	Moderate	Moderate	Moderate
7. Selectivity	Low	High	Moderate	Low	High	High	High	Low	Low	Low
8. Recovery	Moderate	Moderate	High	Moderate	High	High	Highest	High	High	High
9. Dilution	Moderate	Low	Low	Moderate	Low	Low	Lowest	Low	Moderate	High
10. Flexibility	Moderate	High	Moderate	Low	Moderate	High	High	Low	Moderate	Low
11. Stability of openings	Moderate	High	High	High	High	Moderate	High	High	Moderate	Moderate
12. Subsidence	Moderate	Low	Low	Low	Low	Moderate	Low	High	High	High
13. Health and safety	Good	Good	Good	Good	Moderate	Moderate	Poor	Good	Good	Good
14. Other	Highly mechanized, caves with pillar recovery, good ventilation	Mechanized, fair ventilation	Gravity flow in stope, labor-intensive, simple method	Gravity flow in stope, mechanized, large blasts, good ventilation	Gravity flow in stope, mechanized, requires backfill	Gravity flow in stope labor-intensive, simple method	Gravity flow in stope, labor-intensive, high timber cost	Highly mechanized, continuous, rigid, expensive moves	Mechanized, draw control critical	Gravity flow in undercut, low breakage cost, good ventilation, draw control critical

Table 2: Cost per tonne for underground mining methods including prospecting, exploration, development and exploitation but excludes processing and transportation(Hartman and Mutmansky, 2002).



Mining Method	Average Relative Cost,[b] Percent	Range of Absolute Mining Cost,[c] $/ton	($/tonne)
Surface			
Open pit mining	5	2–20	(2–22)
Quarrying	100	25–150	(28–165)
Open cast mining	10	4–20	(4–22)
Hydraulicking	5	2–10	(2–11)
Dredging	<5	1–5	(1–6)
Borehole mining	5	2–10	(2–11)
Leaching	10%	4–20	(4–22)
Underground			
Room-and-pillar mining	20	10–25	(11–28)
Stope-and-pillar mining	10	5–15	(6–17)
Shrinkage stoping	45	30–70	(33–77)
Sublevel stoping	20	12–35	(13–39)
Cut-and-fill stoping	55	30–70	(33–77)
Stull stoping	70	20–65	(22–72)
Square-set stoping	100	50–150	(55–165)
Longwall mining	15	10–20	(11–22)
Sublevel caving	15	10–30	(11–33)
Block caving	10	5–15	(6–17)

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(Contains mining data tables.)

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(Older book but contains many useful formulas for initial cost estimates for different mining methods that are still applicable)

Gertsch, R. E. & Billock, R. L. (ed.). Techniques in Underground Mining, Colorado, Society for Mining, Metallurgy, and Exploration, Inc. 1998.
(Contains multiple papers for underground method selection and all traditional types of underground mining, excluding longwall, and contains cost calculation techniques for each.)

Hartman, H. L. & Mutmansky, J. M. Introductory Mining Engineering, New Jersey, John Wiley and Sons, 2002.
(Explains underground mining methods and takes a brief look at mine economics. Two tables from Hartman & Mutmansky are included: Table 1 shows the pros and cons of various traditional underground mining methods; and Table 2 gives an idea of the cost of underground mining methods).

Hustrulid, W. A. & Bullock, R. L. Underground Mining Methods, Colorado, Society for Mining, Metallurgy, and Exploration, Inc. 2001.
(Contains papers on topics such as: underground method selection, cost estimates for underground mines; room and pillar mining; longwall mining; caving methods; roof support; and mine automation)

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www.westernmine.com – can obtain mine equipment costs as well as software for mine cost analysis.