Socially Accountable Resource Recovery Using Rheological Extraction

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ABSTRACT
There will be no shortage of minerals in the foreseeable future provided new ways to locate the giant ore bodies still hidden within the Earth are successful. The challenge facing the mining industry is not a shortage of resources but making minerals accessible when commodity prices are low and the economic consequences of environmental responsibility are increasing. The new paradigm for the industry will require removal of people from hazardous areas and the maximum utilisation of the resource with minimal surface environmental impact. The risk, for miners, lies in limited R&D resources being devoted exclusively to efficiency improvement rather than new ways of operating. Without due attention to a long-term vision, a technology gap for mining difficult ores in a difficult social environment may appear.

This paper describes three new approaches to mining in the minerals, coal and mineral sands areas, that tread lightly upon the earth by mining with minimal above ground infrastructure or material movement. The new concept explored in this paper is 'rheological extraction': continuous mining machines and processes based on multiphase fluids and their interaction with the geological structure.

Introduction
There have been, and will continue to be, paradigm shifts in mining technology. The shift to mechanisation in the 1950s together with the move to large earth moving equipment in the 1970s changed mining dramatically for the better with respect to safety, health and the environment while providing step changes in productivity. There is now a shift in the larger operations to remote controlled and automated equipment.

In the future, reasons for automation will focus on:

- removing people from the workface
- improving revenue
- maximising the use of a resource
- minimal surface impact

The next major paradigm shift will thus be environmentally sustainable mining that addresses these four criteria through new mass mining methods.

A key issue for future generations will be accessing new types of coal and mineral resources, which are often difficult to access, are in inherently dangerous ground or lie below environmentally sensitive areas. Rheological extraction holds its own in the niche areas of permeable, weak or unconsolidated ground.

The key external drivers come from the need to:

- provide better opportunities for an increasing portion of the world's population, i.e. increase the total resources available and reduce the waste caused by low extraction ratios.
- tread lightly upon the earth for the long term by mining with minimal above ground infrastructure or material movement.
- remove all workers from exposure to underground hazards.

'Socially accountable mining' will be a term familiar to and expected by future generations, yet as different from current practice as 19th century mining practices seem to us. It will no longer be acceptable to sterilise resources through mining methods with low recovery, nor expose workers to underground mining faces.

Mining voids will be used to store mine wastes or create architectural spaces. This is an example of multi-purpose mining, where mining itself may be uneconomic, but the generation of void or by-products has other uses.

Maximum Utilisation of the Resource
Resource recovery is highly dependent on the economics of the mining method chosen. In the case of thick seam coal the mining method, for example longwall, highwall or bord and pillar, dictates that in many cases

the majority of the coal is sterilised to traditional mining technologies. But the induced fracture from previous mining may actually be beneficial to later rheological mining. One example, now being tested in Australia, would be in situ gassification of a goaf. The examples given in this paper have a positive impact on sustainability in the sense that they make better use of existing resources and extend mining options.

Minimal Surface Environmental Impact

The cleaning of coal or upgrading of a metaliferous ore are currently characterised by processing plants occupying a large area of land near the mine. Associated are refuse piles and tailings dams. Waste materials are increasingly considered unacceptable outcomes of a mining operation and if a mine is to proceed, these will not be allowed to remain as a visual reminder of their existence. In many cases this will change the envelope of mining life cycle economics to the point of non-viability in many cases, or impact on the licence to operate. A number of examples of this are starting to emerge.

The concept of rheological extraction implies that the maximum amount of the valuable material will be cut from the reserve in a manner that allows it to be transported from the void in a slurry. This will require the slurry to have particular rheological characteristics to aid suspension of the valuable particles and assist their transport.

The processing plant will need to be mobile to cater for a number of mining voids to be processed sequentially. This implies that the plant's operations need to be high capacity, low residence time devices treating suspensions in a particular manner. These plants will have more in common with chemical plants than current processing plants. Their outputs will be upgraded valuable material in a form that can be quickly transported from the mining site to point of use, and a tailings stream that can be disposed of in a nearby exhausted mining void.

Removal of People from Hazardous Areas

The introduction of remote controlled equipment to remove operators from the immediate working face is being implemented in many mines. Automation of existing equipment provides further opportunities to improve the safety of some of the workforce [Dekker], however some people must still work within the pit. New mining methods made possible by automated rheological extraction allow operation without anyone in the pit. Three such methods are described in this paper: in situ bio-leaching, keyhole coal mining and the SORD and Shield method.

The Technologies

In situ bio-leaching

Perhaps the most familiar mining method based on rheological extraction is leaching. How does such a technique match the requirements for a socially accountable resource? In situ leaching reduces the surface infrastructure, removes people from the mining face, allows unwanted material to remain in the ground and potentially provides a lower cost solution to mining.

The ideal geological environment for in situ leaching is a permeable orebody surrounded by an impermeable structure. Since this cannot be made to order, the orebody may be fractured hydraulically or by explosives. Strategies to contain the process may include grouting, freezing or impressed backpressure using water. In addition, the process itself may be made more benign in terms of impact on the water table. Neither chemical leach nor current biological agents can be regarded as totally benign. What is required is an agent that acts much faster yet becomes inactive under normal conditions.

Microbial leaching approximately doubles in speed for every 10 degrees C increase in operating temperature until the temperature limit for the organism is reached. Unless the rock temperature (and permeability) is within the optimum range, it is likely that pre-fracturing and isolation of the rock mass within a 'stope' boundary to maintain temperature is required for in-situ applications. In some circumstances pre-heating the fluid may be practical. For rock with a heat capacity of 1MJ/tonne.degC and an assumed power cost of 7.2c/kWh, a heating cost of $1 per tonne would be required to raise the broken rock temperature by 50ºC with no heat loss to the walls. The time taken to heat the rock mass would depend on the size distribution, but it can be shown that the time taken is controlled by the power available rather than the rock conductivity [Cengel] provided the rock is broken to sub-metre sizes. For example it would take over six months for 3MW of power to heat one million tonnes of rock by 50ºC.

There has been some use of high temperature microbes such as Sulfolobus, which are optimal at around 70°C for the oxidation of pyrite. About sixty new species of hyperthermophiles [Binns and Dekker] have been discovered since these types of communities were first encountered in the late 1970s in a tectonically active area north of the Galapagos Islands. They grow fastest between 80 and 100°C, and most are unable to grow at temperatures below 60°C, a temperature regime ideal from both a productivity and environmental safety point of view. Most discovered thus far are anaerobic, using sulfur or nitrate to oxidise reductive gases to gain their energy. Recent works has included an international expedition to collect and identify hyperthermophile bacteria and archea from deep-sea hydrothermal vent communities with an ability to oxidise and leach metals from mineral sulfide ores.

Whatever the leaching agent is, chemical or biological, the rheology of the mining process will still be the major controlling factor. Permeability and ground water control are the primary issues. The advantages of using hyperthermophiles relate to increased reaction rates, increased recovery and the ability to close them down by removing their heat source.

Key hole coal mining

Within the Bowen Basin alone at least 2.5 billion tonnes of the world's best coking coal will remain in the ground due to the lack of a suitable extraction technology for high quality coal in structured or geologically disturbed regions, or at depths beyond conventional open cut mining. In addition current mining methods are restricted to extracting a few metres of a seam even if the seam itself is much thicker, sterilising a valuable resource. Keyhole coal mining techniques will enable access to coal resources with difficult geometry or structure that would otherwise remain unmined.

As shown in Figure 1, the concept of key hole mining is to access coal through a small access opening such as a borehole. The mining process is effected by either water jet cutting or by remote automated machinery. The product is a three phase fluid that is returned to the surface where coal, gas and water are separated. The water is used in the associated process plant and recycled after cleaning. The gas is prepared for power generation or disposal and the coal washed for transport and sale. Fine tailings and course reject may be mixed with other additives before being placed back underground through a previous extraction hole as shown in Figure 1.

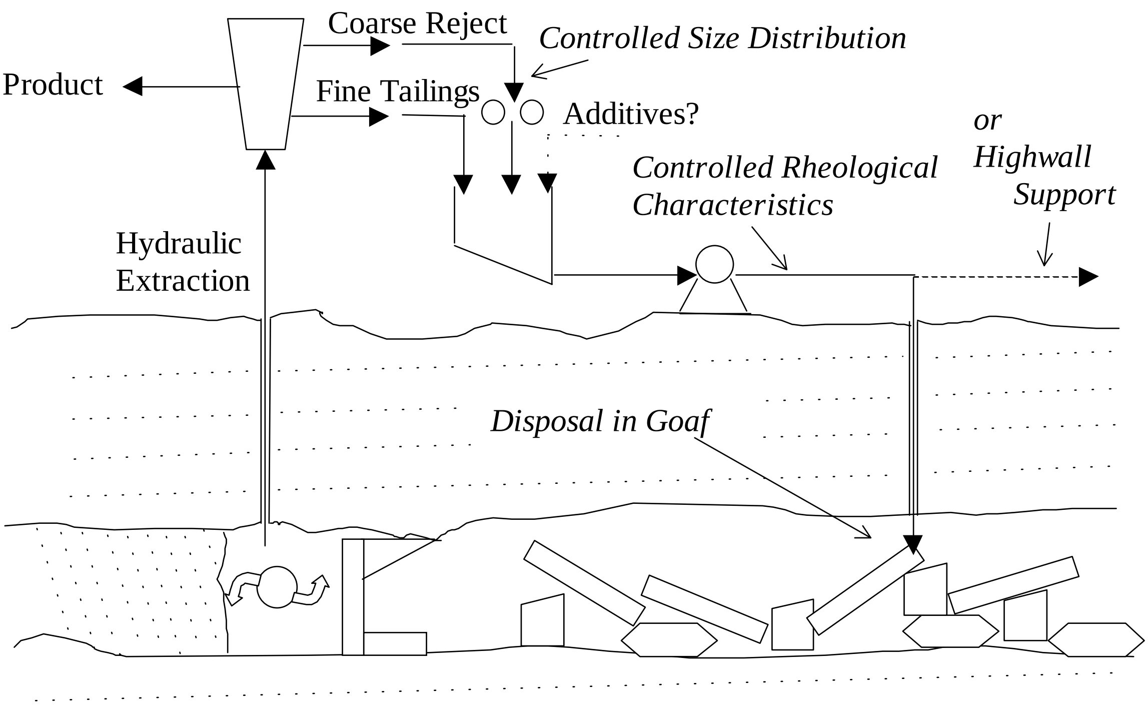

Figure 1. In Key hole coal mining, the mining may be conducted through a single opening, or with a second extraction borehole. A key feature is the return of waste materials to previously mined voids.

Further progress will depend on a significant understanding of:

- cutting solids with fluids
- suspension and transport of solids
- geomechanics and measurement and of fluid filled voids
- controlled separation of slurry components.

SORD and Shield
SORD and Shield is another keyhole mining technique ideal for unconsolidated materials. This is particularly effective where large stripping ratios can be avoided. SORD (Subterranean Ore Recovery Device) and Shield (an extendable umbilical) is an approach invented by Sord Technologies Ltd. and being developed in collaboration with CSIRO. Figure 2 shows the basic concept that looks much like a WW1 tank with tracks above and below.

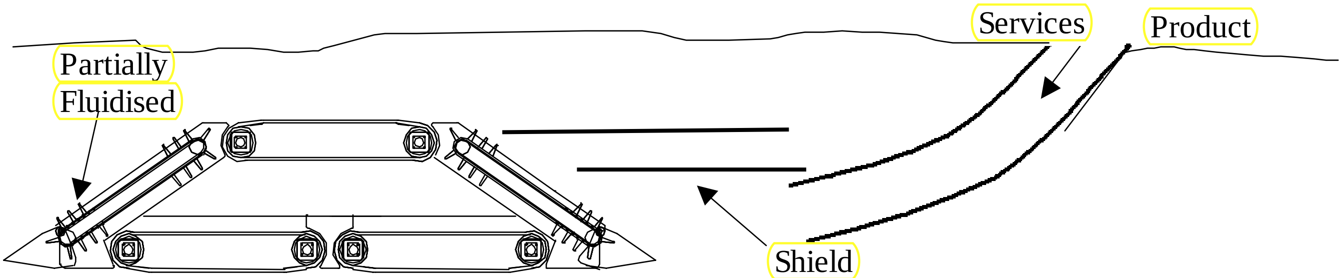

Figure 2. SORD and Shield

When mining, SORD partially fluidises a slurry which enters through a screen for pumping to the surface through pipes within the Shield. There are screens front and back cleared by moving tines. After travelling forward, SORD retraces its path, pumping tailings into the cavity it leaves behind. Geophysical and navigational sensors keep the SORD on track. The genius of the system is Shield, which is a patented self extending tube created at the SORD head as it travels so that Shield remains stationary with respect to its surroundings.
SORD and Shield has the potential to revolutionise mining of unconsolidated sand and gravels by making underground mining of these types of deposits practical. This eliminates the need for large stripping ratios in sand mining and the return of tailings inherent in the method reduces subsidence. Minimisation of surface impact may be achieved by moving operations underground.
SORD and Shield was invented originally as a means to access gold in the Victorian 'Deep Leads' paleochannels, where many millions of ounces of gold remain because there is currently no environmentally acceptable mining method.

Key Research Areas
Three quite different examples of new mining methods based on automated mining have been given that illustrate the paradigm shift required to address the future need for socially accountable mining. Each also has the potential to improve the economic sustainability of the deposit types targeted.
To achieve the objectives, significant innovation in sensors and control technology is required. This will require research into surveying of underground cavities, microsensors and devices for monitoring and control of multiphase fluids, guidance of machines through fluids and robotic sensing of ore grade and geology.
The physical process of mining will require new automated machines of all sizes and/or biological and chemical nanotechnologies. New cutting tools and methods that produce nicely diced coal or ore with minimal fines production that can be pumped will be linked to water handling issues, valuable component concentration and final placement of tailings underground. Technology gaps include intelligent machines that can sense the geology and act accordingly specifically designed for access to difficult areas by creating a slurry ahead of their path or by 'transforming' their shape or configuration. A fundamental understanding of chaotic behaviour in multiphase fluids will be required to control the extraction and concentration processes without human intervention
Research will also need to focus on continuous processes such as reaction transport, biological enhancement and establishment of in situ natural reactors. We also need to study how in situ bio/nano solution technology can artificially enhance rock permeability and how water or reagents might modify in situ strength of the ground.

Conclusion
A key objective for the future is the recovery of resources, some of which are currently inaccessible or sub-economic, without exposing people to the mine face and having acceptably low impact on the surface environment.

It is essential that those techniques that have potential to make marginal deposits economic be also applied to orebodies that are currently mined economically using conventional methods. This will give a much higher return to investors and thus help attract exploration and mine development funding which would otherwise end up in other more attractive investments.

Rheological extraction is an approach worthy of more attention given its potential to resolve many of the key environmental issues. The risk, for miners, lies in limited R&D resources being devoted exclusively to efficiency improvement rather than new ways of operating. A technology gap for mining difficult targets will otherwise appear just when demand requires those resources.

There are a number of activities to progress:

- Identify the real opportunity areas for these concepts and establish economic boundaries and impacts.
- Identify the technology gaps.
- Establish the R&D program to address the technology gaps.
- Look forward to a more profitable future with high community acceptance.

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