Predicting the environmental effects of mining

On the Queensland coast, between Rockhampton and Gladstone, lies the site for Australia's, and possibly the world's, largest mine.

The V-notch box at the head of the experimental stream at Rundle. It enabled the scientists to control flow rates.

A joint venture — comprising Esso Australia Ltd, Southern Pacific Petroleum NL, and Central Pacific Minerals NL — is conducting a feasibility study of the proposed mine at the Rundle oil-shale deposit, which contains an estimated 4000 million tonnes of shale. If development goes ahead, each tonne of shale mined will yield, on average, half a barrel of oil.

Mining will also produce wastes, of course, from both extraction and processing of the shale. Leaching of pollutants from waste dumps, or accidental spills into drainage streams, could affect the surrounding environment.

Experience at mines elsewhere has shown that dissolved metal ions — such as copper, aluminium, zinc, cadmium, and lead — can pose problems, but how important these may be at Rundle is difficult to assess. To throw light on the matter, scientists at the CSIRO Division of Fossil Fuels in Sydney have been studying the physical and chemical processes that control the fate of heavy metals from mining operations. The group, headed by Dr Bernard Chapman, recently assessed some of the possible environmental hazards posed by the establishment of a mine and processing plant at the Rundle deposit.

Down in the dumps

Australia has quite a history of involvement in the production of liquid fuels from the retorting of oil shale (see *Ecos* 27). However, since operations ceased at the Glen Davis shale mine in New South Wales in 1952, no further exploitation of this resource has taken place.

The Rundle oil-shale deposit covers an area of about 25 sq. km. The Esso company's proposals for developing the resource include a target production of 17 000 barrels per day in the late 1990s, with a final target of 75 000 barrels per day by early next century. Such an output requires the removal of about 1 million tonnes of rock per day from a pit that could reach depths of up to 300 m.

As well as the waste rock removed from on top of (and between) the shale seams, the proposed mine will generate large quantities of spent shale from the retorting process. Much of this solid waste will end up in surface dumps. While the dumps will be designed to minimise leaching, rain could leach pollutants into nearby streams; these empty into estuaries, and finally the sea.

Dr Chapman and his colleagues wanted to find out what ions might leach out of the dumps, and how easily they could find their way through to streams. And once the toxic ions arrived there, how long would the fresh-water environment take to get rid of them? Would they reach the more diverse estuarine and marine ecosystems?

Leaching studies

Strangely enough, one of the most important processes that can cause metal leaching in waste dumps is not chemical but biological. Some bacteria, particularly those belonging to the genus *Thiobacillus*, thrive in acidic environments and convert sulfides such as pyrite (iron sulfide) into sulfuric acid, which in turn leaches metals. This oxidation reaction also releases energy, which can cause the temperatures inside some base metal sulfide dumps to reach 60°C.

In fact, leachates from spent shales are alkaline — they contain calcium and magnesium oxides formed during retorting — and *Thiobacillus* species do not operate effectively under these conditions. However, some species of bacteria can thrive in alkaline conditions and produce acid, eventually allowing *Thiobacillus* to take over if the acid-neutralising capacity of the dumps is exceeded.

A computer model is being used to predict the fate of metal ions released from mining wastes.

Dr Chapman, together with Dr David Jones and Mr Robert Jung, of the CSIRO group, set up laboratory experiments to identify the metal ions that might be leached out of mining-waste dumps at Rundle. They initially chose a technique known as batch leaching. Since it can be carried out quickly, the scientists could rapidly get an idea of the dissolved sub-

stances capable of causing environmental concern.

In the event of mining operations at Rundle, waste shale, claystone from between the seams, and spent shale from the retorting process will constitute the main materials in dumps. Because these different rocks contain varying amounts of pyrite (acidifying) and carbonate (de-acidifying), a range of pH values is likely to occur in the dumps.

In their batch leaching experiment, the three researchers put slurries of the dump materials into a series of vessels having a range of acidities. They used sulfuric acid in distilled water as the leach solution. This set-up allowed them to see which metals leached at a particular pH, and they also noted that one of the materials, Kerosene Creek raw shale, developed a high acidity when mixed with water for a prolonged period in a batch reactor.

During batch leaching, however, a waste material experiences very different conditions from those likely to be found in a waste pile. Another technique, column leaching, more closely approximates the real thing.

The CSIRO group packed column-shaped vessels with different materials, including a mixture of raw and retorted shale and claystone, and dripped water through them. The flow rate was high — equivalent to about 33 m of rainfall per year — to accelerate the leaching process. On an actual dump, transpiration by surface vegetation would prevent or reduce the build-up of water and leaching might take decades to occur, if it occurred at all.

Dr Chapman, Dr Jones, and Mr Jung also kept the columns at the fairly high temperature of 35° C, to further accelerate the rate of chemical and bacterial reactions. They inoculated some of the columns with acidifying bacteria. After 7 months, as no evidence of acidification appeared, they replaced water as the leaching agent with dilute sulfuric acid to determine the type of leachate that might be produced should natural acid production exhaust the considerable acid-neutralising capacity of the available carbonates.

The column leaching tests showed that thiosulfate — an oxidation product of sulfide — was the major trace component in leachate from columns containing retorted shale only. Oxidation of the thiosulfate, in turn, produces sulfates that acidify water. But when the retorted shale was mixed with raw shale and claystone, thiosulfate did not leach.

The results indicated that, if the pH in the dumps were to fall significantly, soluble forms of copper, zinc, nickel, arsenic, and, of course, acid might be produced. The behaviour of copper and arsenic appeared to be a little more complex than that of the others.

Copper has a high affinity for suspended organic humic materials, and can extend its life in solution by hanging on to these molecules, avoiding adsorption onto bed sediments or precipitation out of solution.

In the case of arsenic, because freshly retorted shale is quite alkaline, the negatively charged arsenate ion is held only weakly and will leach out. However, as the shale ages, carbon dioxide from the air reduces its alkaline nature, causing the arsenic to stick to it more strongly and greatly reducing the rate at which it leaches.

Creating a stream

The next step in the research was to observe what might happen to acid and metals if they moved downstream from the dumps. Obviously, pouring metal-containing solutions into local permanently flowing streams was out of the question. The three scientists came up with a novel answer: they created a stream by pumping water from a nearby permanent creek into a normally dry stream-bed.

Although it sounds simple — by biblical accounts, anyway — making a stream turned out to be a sizeable project in itself. First, the research team had to set up tubing and a pump to convey water from the source. The water then flowed into a calibrated V-notch weir box, which allowed them to control the stream-flow rate.

Wandering scrub cattle caused problems, so they erected an electric fence around the study area. And after 5 weeks' work getting the stream-release experiments under way, heavy rains caused extensive local flooding, putting Dr Chapman and his team back to square one!

A second attempt a few months later proved successful. The group set up six sampling stations along the 560-m length of the stream for monitoring the progress of metal solutions, which they poured in just downstream of the V-notch weir.

After it had flowed the length of the study section, the ephemeral stream continued on for another kilometre before rejoining its source — Munduran Creek. The CSIRO group had to ensure that at this point the concentrations of any introduced metals were within acceptable limits. Their monitoring showed that, in fact, concentra-

Rundle shale.

Filling the experimental creek.

The start of a copper-release experiment.

tions of these metals had been reduced to well below internationally accepted limits for drinking or irrigation water.

Before releasing any metals or acid into the water, Dr Chapman's group carried out studies to identify the patterns of water movement in the stream. For this, they chose non-reactive tracers — the red fluorescent dye, Rhodamine WT, and lithium bromide.

Why is water movement so important to the fate of mine-waste pollutants? The answer is that physical processes such as advection, dilution, dispersion, and sedimentation can reduce the levels of metal ions and acid in affected streams. Advection is simply the bulk flow of the water, while dilution occurs through tributary and groundwater inflow. Dispersion in water occurs in much the same way as smoke disperses in air — a spreading and thinning-out process. Sedimentation is the result of suspended particles settling out onto the stream-bed.

Results from the Rhodamine WT tracer studies in the Rundle stream indicated that the rate of water flow along its course varied greatly, making it a far more complex system than the simple man-made watercourses that have, until now, been used in predictive studies.

One interesting observation made was that, when stream flow was low, thermal stratification developed in the deeper pools during the day when heat from the sun warmed surface layers. These warmer layers, being less dense than colder water, did not mix vertically. This could lead to a 'short-circuiting' of some pools, with inflowing waters simply skimming across the colder, lower layers. As a result of this process, dissolved pollutants — if released overnight — could become trapped in the bottom layers as the water warmed up.

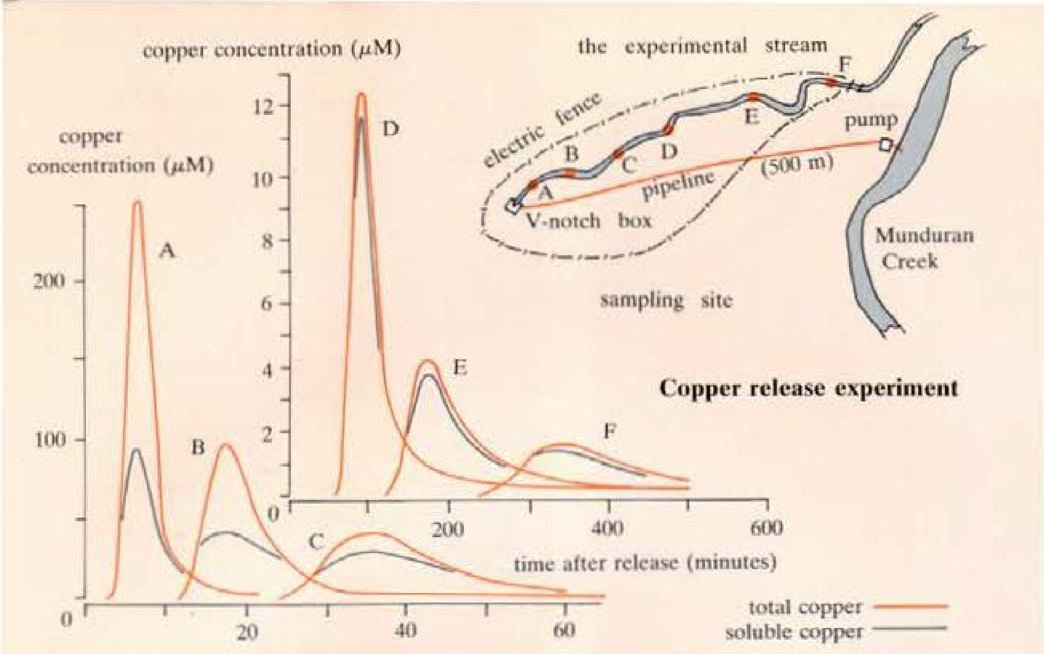
Metals and acid

After completing the tracer studies, the scientists were ready to release heavy metals and acid into the stream. Since their column-leaching experiments had indicated that waste-dump leachate might include arsenic, nickel, zinc, and copper, they poured solutions containing ions of each of these elements into the stream. Doses of sulfuric acid were also tested, separately and together with the solutions containing metal ions.

Copper turned out to be the element most readily removed from solution along the stream's course. This was followed by zinc, then nickel and arsenic, with acid the most 'mobile' of all. In fact, about 80% of the copper put into the stream did not reach the last sampling station, while almost 80% of the arsenic did make the distance.

Where did the metal ions go? In a stream, chemical processes as well as physical ones control the transport of metals and acid. Important chemical processes include solution reactions, in which soluble complexes are formed. Ions can also be adsorbed onto sediments on the stream-bed or onto suspended particles above; or they can precipitate out of solution if they exceed certain concentrations. Dilution, however, can counteract precipitation, causing particulate metals to re-dissolve.

Release of a red dye, Rhodamine WT, enabled the scientists to study water movement patterns in the experimental stream.



As introduced copper moved down the experimental stream, the maximum concentrations recorded declined sharply from one sampling site to the next.

In the Rundle stream-release experiment, copper precipitated as the fine milky-blue colloid known as malachite. (Copper can form malachite when it reacts in solution with high levels of bicarbonate.) The solid did not settle out on the stream-bed, but was instead carried downstream by the flowing water.

As the concentration of copper in the water pulse decreased due to dispersion, the malachite began to re-dissolve into its ionic components. Removal of copper from the water appeared to occur through binding of the dissolved copper to sediments on the bed of the stream.

Dr Chapman, Dr Jones, and Mr Jung found that low levels of acid — released into the stream at the same time as copper, zinc, and nickel — caused the metals to remain longer in the flowing water. Possibly, the acid 'competed' with the metals for reactive sites on stream sediments. At high acid concentrations, copper, manganese, iron, aluminium, and silicon were actually scavenged from stream-bed sediments. These re-dissolved metals were eventually re-absorbed or precipitated as the acid became diluted further downstream.

From the laboratory leaching and stream-release experiments, the CSIRO group could make recommendations on the disposal of wastes from a future oil-shale mining venture at Rundle. As a priority, the operator would need to determine the pyrite and carbonate content of the material mined, to ensure that any possibly acidifying material — such as waste from the Kerosene Creek seam — would not be placed undiluted into dumps. Rather, it should be mixed on site with wastes having a high carbonate content or high pH — for example, claystone and freshly retorted and combusted shale.

The study indicated that small infrequent releases of pollutants in seepage would not reach coastal estuaries, but would be caught in stream-bed sediments. On the other hand, regular releases or a large spill — through a dam bursting, for example — would make the waste water flow too quickly for chemical processes to take the pollutants out of solution before they reached coastal ecosystems.

The researchers have outlined some goals for a possible second-stage study, including further stream-release investigations to provide more details on sediment interactions. One question that remains unanswered is: how long will the reactive sites on the stream sediment hold out before they exhaust their capacity to capture pollutants?

Computer model

The metal-release studies in the Rundle stream were designed to provide input data for a computer model, developed by Dr Chapman's team, that is being used to predict the fate of metal ions released from mining wastes. These data, together with information obtained from similar studies planned for different locations, will enable the model to be 'calibrated in the field'.

The scientists expect that eventually the computer model, in conjunction with laboratory tests to measure rates of uptake of metals by samples of stream sediments, will enable the transport of metals in creeks and rivers to be predicted with a fair degree of accuracy. This will reduce the need to carry out tests involving the release of metal ions into the environment.

A 'transport' component in the model includes considerations of how fast the ions move downstream. The other component, a 'chemical' one, takes into account the chemical processes of simple ionic interactions, hydrolysis, precipitation, oxidation and reduction, and gas–liquid and adsorption reactions. To get an idea of the number of 'reactive' sites on stream sediments, the scientists collected samples of sediment, dried them, and later analysed them in the laboratory.

Dr Chapman and Mr Jung, together with colleagues Dr Robert James and Mr Hayden Washington, had earlier applied the model to an acid mine-drainage stream in New South Wales. They chose Daylight Creek, which drains silver-, copper-, lead-, zinc-, and gold-mine workings abandoned last century. Daylight Creek is at Sunny Corner, near Lithgow, N.S.W.

In a type of anti-pollution experiment, they injected a pulse of an alkaline solution into the stream — made acid by bacterial activity on the mining wastes — to see which metals precipitated out.

The scientists' observations agreed well with the computer simulation of the experiment. Subsequent detailed studies of this stream and other mine-drainage streams have enabled them to identify many of the processes responsible for the removal of metal ions downstream from this type of pollution source.

Dr Chapman believes that, as a predictive tool, the computer program will be applicable to both environmental impact assessment and the day-to-day management of plant effluents. Industries are now tapping CSIRO expertise in this area, and large companies are substantially funding continuing investigations.

Mary Lou Considine

More about the topic

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