Information Circular 9432

Mechanical Excavation Systems

(In Three Parts)

3. Environmental Applications

By John A. Lombardi and Charles V. Jude

UNITED STATES DEPARTMENT OF THE INTERIOR
Bruce Babbitt, Secretary

BUREAU OF MINES
Rhea Lydia Graham, Director

PREFACE

The results of U.S. Bureau of Mines (USBM) research on mechanical excavation mining systems are presented in a three-part Information Circular (IC) series. Part 1 deals with narrow-vein and longwall mining concepts using the USBM-developed radial-axial drill-split tool. Part 2 presents concepts in stope leaching and stope autoclave mineral recovery systems using the drill-split narrow-vein and longwall mining methods described in part 1. Part 3 is a review of potential environmental applications for the drill-split narrow-vein and longwall methods described in part 1, including the development of "vertical landfills" near urban centers.

The USBM research presented in this series is conceptual in nature. The concepts were presumed technically feasible and were costed. The costing of conceptual designs that use technologies that have no commercial track record is approximate. Wherever possible, cost estimating was guided by the USBM's Cost Estimating System Handbook* and USBM IC "Simplified Cost Models for Prefeasibility Mineral Evaluations."** Where these cost sources were not applicable, the best available literature was examined and engineering judgments were used. Costs are for comparative use only and are in 1984 dollars. Conservative estimates of technology productivities were used in the cost-estimating exercises; however, only further development and demonstration of the proposed technologies can validate the cost estimates in this IC series. Although many components of the proposed mining systems are conceptual, the combination of all component costs that comprise a system will produce a reliable prefeasibility-type cost estimate. Prefeasibility cost estimates are best used in acceptance and rejection decisionmaking; for the mining systems proposed in this IC series, this level of decisionmaking makes single component cost tracking inappropriate.

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*U.S Bureau of Mines. Bureau of Mines Cost Estimating System Handbook (In Two Parts). IC 9142, 1987, 629 pp.; IC 9143, 1987, 566 pp.

**Camm, T. W. Simplified Cost Models for Prefeasibility Mineral Evaluations. USBM IC 9298, 1991, 35 pp.

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ILLUSTRATIONS

UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

g	gram	m^2	square meter (area)
g/t	gram per metric ton	t	metric ton
m	meter		

MECHANICAL EXCAVATION SYSTEMS

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ABSTRACT

In this U.S. Bureau of Mines report, proposed narrow-vein and longwall mining concepts using drill-split technology (described in part 1 of this series) and in situ liner concepts (described in part 2 of the series) are combined and applied conceptually to environmental problems.

Proposed applications deal with (1) acid mine drainage (AMD), (2) solid waste disposal, (3) site remediation, and (4) pollution prevention through innovative industrial design.

For control of AMD from abandoned hillside mine workings, it is proposed that source veins be re-mined, processed for residual values, then backfilled using an impermeable compound backfill mix. For solid waste disposal, "vertical landfills" are proposed, consisting of trash-backfilled underground rock quarries. Vertical landfill activities take place in in situ lined containments that geohydrologically isolate the mining-backfilling activities. Site remediation through the creation of in situ underliners, for the capture of toxic leachates, and pollution prevention through the underground storage of toxic, flammable, and explosive materials in in situ containments, are proposed.

[1]Mining engineer, Denver Research Center, U.S. Bureau of Mines,. Denver, CO.

INTRODUCTION

U.S. Bureau of Mines (USBM) research in the area of mechanical excavation mining systems has identified the drill-split drill-hole-excavation technique to have a significant potential for environmental use (*1*).[2] The radial-axial drill-split tool, when used in its narrow-vein and longwall channeling modes as described in part 1 of this series (*2*), can create wall-like openings underground. When backfilled with impermeable compounds, as described in part 2 of the series (*3*), these openings can be formed and joined to create (1) close-topped encapsulated in situ containments, (2) open-topped in situ catchments, (3) in situ groundwater flow channels, and (4) groundwater flow diverter surfaces (figure 1). Wall-like in situ constructions can be used to barricade, collect, channel, and vat-retain contaminated groundwaters. In situ containments can also be (1) backfilled with solids, e.g., trash, or (2) backfilled with materials engineered to maximize pore space to effect the pore space storage of fluids and compressed gases.

Combinations of in situ liner construction forms may be used for additional purposes. Groundwaters can be captured by in situ liner diversion surfaces and funneled into in situ "packed bed" ion-exchange pipes where contained groundwater can be demineralized by the ion-exchange resin in the pipe. This technique may also be used for primary metals recovery from mineralized brines.

In all of the proposed drill-split environmental uses, the identification of liner backfill materials suited to the control of targeted fluids, gases, or toxic leachates is required. The fill must be chemically resistant, fluid and/or gas impermeable, and compressible without cracking to accommodate ground movements around the excavations. A German firm proposes the use of a sand and sodium silicate compound as a leachate control liner beneath landfills (*4*). The German-proposed sand and sodium silicate fills are reported to remain slightly plastic for centuries; hence, any fill disruptions due to differential ground movements would reseal by a process called autogenous healing. Sand and polyurethane backfill mixtures, asphaltic cements, and flue-gas-desulfurization (FGD) compounds are other candidate backfill materials. Sand-polyurethane fills are cellular in texture and will crush and compress, not crack, under rock mass loading. Additional research on the compression response characteristics of asphaltic and FGD compounds is required.

As with any gas, solid, or liquid separation barrier, in situ liners can be constructed in layers. Either within the same excavation, or in separate parallel-plane excavations, porous drainage layers can be interleaved, singly or redundantly, with impermeable barrier layers.

IN SITU LINERS: GENERIC ENVIRONMENTAL USE PATTERNS

As presented in parts 1 and 2 of this series (*2-3*), planer, radial-axial drill-split channel cuts, when backfilled with impermeable compounds, form in situ solution flow barriers, i.e., in situ liners. As shown in figure 1, the barriers can be rectilinear, convoluted, or involuted surfaces, and they can be joined and formed to create six-sided total enclosures, five-sided vats, four-sided channels or tubes, and three-sided planer diversion structures. In situ liner constructs are not load-bearing structures. The liners are soft to semirigid backfills layered into the earth with hard-rock pillar confinement on all sides. The loads (redistributed stresses) associated with the construction and operation of an in situ vat, tube, enclosure, etc., will be carried by the hard-rock pillars astride the liners.

Six-sided in situ enclosures can be used to contain substances, as in the geohydrologic isolation of mining wastes, municipal wastes, etc., or to isolate substances, as in the creation of dry "cofferdam" zones below the water table. Accordingly, trash and toxic solids may be securely stowed in geohydrologically isolated encapsulation zones, which are located tens, hundreds, or thousands of feet beneath their point of origin. Also, flammable-explosive liquids and gases can be safely stored without excursions in the pore spaces of backfilled encapsulated zones.

Five-sided in situ vats, used as underliners, can capture and store meteoric and surface water flows. When designed to capture and hold seasonal waters in near-surface containments, these in situ basins function as shallow aquifers. If the in situ vat is placed under contaminated ground, the vat can be used as a control sump like a subsurface holding pond for meteoric waters. Similarly, treatment chemicals can be pumped onto a contaminated property and collected in the in situ vat, then removed and treated to effect property rehabilitation.

[2]Italic numbers in parentheses refer to items in the list of references at the end of this report.

Four-sided in situ tubes can be used to channel solutions from one underground stratum to another. The tube constructions can be backfilled with filtering sands, charcoal, ion-exchange media, and/or biotreatment agents to effect in situ water treatments coincident with transport. The tubes can be plumbed for backwash stripping of the packed bed media to allow for media regeneration and reuse.

Impermeable in situ surfaces can be constructed to divert groundwater flows in areas where water mixing and/or expression onto the surface are undesirable (e.g., salt springs, mining district drainage tunnels, etc.).

IN SITU LINERS: SPECIFIC ENVIRONMENTAL USES

Environmental uses of in situ liners are divisible into reactive (remedial) and proactive (preventative) uses. In the reactive uses, the technology is brought to bear on existing conditions, such as the control, collection, and/or treatment of spilled substances. In proactive uses, the technology founds or is part of a re-engineered, pollution-preventing process.

Among the environmental problems in need of remedial or preventative technological redress are (1) air and water contamination, (2) toxic and waste solids storage and disposal, (3) hazardous, flammable-explosive liquid and gas transportation and storage, (4) noise pollution, and (5) visual pollution. Directly and indirectly these problems exact economic and health maintenance tolls on society in the form of reduced work force productivity, lowered real estate values, and litigation and the fear of litigation (the latter suppresses experimentation and innovation). Precise calculations of the financial effects of an adverse environmental condition are problematic given the indeterminate nature of the lost productivity, real estate, fear of lawsuit, etc., components that make up the cost calculation. What is generally accepted is that the costs of pollution are large even if precise cost-benefit comparative data are not readily available.

The costs of construction of in situ liners are developed in parts 1 and 2 of this series. The application of these cost estimates to the creation of in situ liner environmental structures is easily done, albeit with the uncertainties related to the cost estimation of prototype earth construction equipment and techniques.

ENVIRONMENTAL USES WITH CALCULABLE FINANCIAL BENEFITS

Given that most environmental problems have estimable mitigation costs but inestimable monetary benefits, two in situ liner environmental uses were identified that, uncharacteristically, have both quantifiable costs and benefits. These applications are thought to be ideal technology development vehicles because they have well-defined investment, investment recovery, and potential profitability schedules.

Remining Control of Acid Mine Drainage From Hillside, Vein Adit Sources

In this AMD control concept, the vein would be fully excavated using a modified narrow-vein drill-split mining technique that enables the extraction of medium-width veins. The excavated ores would be processed to recover metal values, and the spent, processed rock, mixed with an impermeable compound binder, would be returned to the mining void as backfill.

The process of AMD control by the above-described extraction-backfill technique includes (1) driving a horizontal vein undercut, (2) creating a vertical raise to the surface from the inby terminus of the undercut, and (3) driving a "grassroots" level incline drift to serve as a vein overcut extending from the undercut level (outby) to the top of the raise (figure 2). A "wall-walking" drill-split narrow-vein jumbo, modified to cut veins 1.8 to 2.4 m wide, would be introduced into a stub raise connecting the vein undercut and overcut using the narrow-vein technique. At the conclusion of mining, the vein will have been replaced 100% by impermeable backfill; there will be no drainage of any type emanating from the replaced vein structure.

The costs of this vein extraction-backfill AMD control technique would be \$40 to \$85/t (\$15 to \$20/t for mining, \$5 to \$35/t for processing, and \$20 to \$30/t for backfill). This cost reflects a modest economies-of-scale productivity increase over the productivity and costs shown in part 1, page 5, of the series (*2*) for the mining of narrow veins that are 0.6 to 1.2 m wide. The processing charge covers the full range of potential ore treatment options, from low-cost heap leaching to high-cost autoclaving, roasting, three-product flotation, etc. (*5*). Backfill costs are derived from the costs shown in part 2, page 8, of this IC series (*3*).

The revenue structure for the proposed AMD control technique is the value of the metals recovered from the extracted vein ores. In the case of a gold ore with a simple, 90% effective vat leach recovery, a zero-net-cost AMD remediation is attained with a 5.0-g/t Au head assay (\$11.25/g Au).

Head assays in the 1.6- to 4.7-g/t Au range (or equivalent value in other metals) are common in the veins of the historical mining districts of the U.S. West, an area in which the proposed AMD control technique would be deployed. Although AMD control in these veins would lose money, it is also often true that there are anomalous, high-grade ore pods in the veins. When all the veins in a district are remined for AMD control, these high-grade pods will be unearthed, and the profits associated with the extraction of the high-grade ores can be used to subsidize AMD control efforts in lower grade veins. The possibility for this high-grade pod "nugget" effect to create revenues in excess of costs on a district-wide basis may support the creation of a profits-driven, speculative AMD control industry.

"Vertical Landfills": Underground Rock Quarries With Waste Disposal

In this mechanical excavation and in situ liner mining system, bedrock materials would be quarried underground from in situ lined enclosures, and municipal-industrial trash would be stowed in the voids created by the quarrying process. The economic attractiveness of the system is predicated on the creation of mines that are close to both the rock product users and the trash generators, i.e., are directly beneath populated urban-suburban areas. By providing rock products and landfill services in the middle of the use and/or need zone, overland haulages are reduced by an order of magnitude over the existing supplier system. Figure 3 is a schematic of the proposed vertical landfill mining system.

Vertical landfills are environmentally attractive because they are out of sight and visually nonpolluting. By moving rock quarrying and landfilling activities underground, they also eliminate the significant windblown dust and trash debris problems associated with surface rock quarry-landfill facilities. Lastly, reduced truck haulage distances lessen air pollution and road damage.

A vertical landfill situated in an urban area will be controlled by the environmental acceptability of the surface load-out (rock) and load-in (trash) headframe facilities. Load-out and load-in activities could probably be sited at the intersections of major traffic arterials (freeway interchanges), in industrial parks, and in "lower" downtown warehouse districts without excessive permit difficulty. In the latter downtown scenario, the shaft headframe could be housed within a warehouse, which, from the outside, would look identical to the other warehouse buildings in the area. Trucks would (1) enter the facility and drop off trash-loaded containers, (2) pick up containers loaded with rock products for delivery, (3) after delivery, circulate in the community and fill the container with municipal-industrial trash, and (4), return to the warehouse with trash-loaded containers to complete the cycle.

The order of underground construction events for vertical landfilling will be heavily influenced by the presence of groundwater. If groundwater is present at the mining horizon, it is essential that the trash backfill not come in contact with groundwater resources. To avoid trash-groundwater contact, the in situ liner encapsulation of the mining-backfilling zone will need to be constructed prior to any quarrying and trash backfilling activities.

Vertical landfill revenues would come from both rock products sales and the acceptance of trash ("tipping") fees. Rock products are available in most urban marketplaces for $4/t, excluding delivery costs, and landfill commodities can be dropped off at the landfill site for $30/t. Given these revenue structures, each metric ton of underground quarried material will produce at least $4 in rock product revenue and $10 in trash stowage fees (this assumes a trash backfill specific gravity of 1.0). As shown in part 1, page 7, of this series (*2*), the drill-split longwall mining cost of hard rocks, delivered to the surface as pea-sized gravel, exclusive of backfilling, is (nominally) $4/t. In part 2, page 8, of the series (*3*), economies-of-scale in situ containments are estimated to add $2/t to rock product costs. If all other infrastructure and operating costs, e.g., shaft construction and maintenance, headframe housing, product bins, and load-in and load-out container-handling gear, mine ventilation, administration, etc., are estimated to add another $1 to $2/t, the mine-mouth cost of coarse-crushed rock products from an enclosed underground quarry is $7 to $8/t.

As described above, the cost of trash handling on the surface and delivery underground for use as backfill could determine the economic practicality of the vertical landfill system. In reality, these "costs" could become "revenues" based on the operation of a state-of-the-art Materials Recovery Facility (MRF) in the headframe area. MRF's are a product of the materials conservation ethic evolving in the country that dictates the recycling of materials to the maximum degree possible. The operation of an MRF at the mine mouth may create the revenue offset needed to sort and prepare nonrecyclable trash for transport underground. The nonrecyclable material sent underground for use as backfill is envisioned to be a "trashcrete," i.e., a hammer-milled, limed, quick-set cement and trash blend.

ENVIRONMENTAL USES WITH INDETERMINATE FINANCIAL BENEFITS

A number of potential environmental uses for in situ liners were identified that have indirect revenue structures, e.g., are of value either because in situ liner remediation alleviates a problem and precludes litigation, or in situ liner use proactively enables a land use change that creates real estate value where little or no previous value existed.

Toxic Solid Waste Burial (Remedial)

One common prescription for the cleanup of contaminated lands is the excavation and transport of contaminated materials to a licensed toxic waste landfill. The locations of toxic waste disposal facilities are usually hundreds of miles distant from the contaminated site, and long, expensive, overland haulage is required. An alternate remediation approach for the affected site is the onsite, deep burial of wastes in an in situ lined encapsulated zone. In such a scenario, a cubic meter of disposed volume for a single-lined containment would cost $25; for a double-lined containment, $30; for a triple-lined containment, $35, etc. Each cubic meter of disposal zone would hold 1 to 2 tons of waste. Onsite burial circumvents the need for overland haulage and eliminates associated spill and accident risks.

Diversion, Capture, and Treatment of Contaminated Groundwater (Remedial)

Contaminated groundwaters that flow through hard-rock structures and exit to the environment through wells, springs, and drainage tunnels can be diverted by barriers created by in situ liners. In the case of surface contamination that sits directly on bedrock, an in situ vat can be constructed beneath the site to collect contaminated meteoric waters. The collection vat will eventually fill unless an emptying system is designed. Potential vat-emptying designs include (1) the creation of a wetland on the contaminated property surface for the biofixing of contaminants and evapotranspiration of fluids or (2) the creation of a packed-bed ion-exchange column at the bottom of the vat through which captured fluids pass and are detoxified during gravity egress from the in situ vessel. Another use of the vat technique is as a catchment used with the purposeful release of cleansing solutions onto the property surface for contaminant stripping. Cleansing solutions would be recovered from the vat by onsite wells, the contaminant stripped, and the cleansing solution regenerated.

Underground Storage of Volatile Liquids (Fuels) and Compressed Gases (Proactive)

The engineered backfilling of an in situ liner encapsulated zone to maximize pore space enables the pore-space storage of liquids and compressed gases. Some liquids and gases, when stored on the surface, are a danger to the surrounding community, industrial complex, etc. Underground storage creates a protective hard-rock barrier between occupied working and living spaces on the surface and the stored liquid or gas commodities in the event of a conflagration, vessel breach, etc. In one special application of this technique, solar thermal-generated acetylene, hydrogen, and syn-gas commodities that are diurnally or seasonally produced can be stored underground under pressure for use throughout the year. In essence, this creates a wellhead-exploitable, regenerable, artificial bed of pipeline-quality pressurized gas.

Freshwater Storage (Proactive)

From parts 1 and 2 of this series (*2-3*), costs of impermeable compound underliners (1.6 m thick) of $50 to $60/m^2 can be deduced. The creation of an aerially expansive horizontal liner with sidewalls creates a meteoric water catchment for seasonal waters that come onto the surface and percolate downward through existing rock mass fracture systems. In many areas, meteoric waters seep deep into the earth and are uneconomic to recover for agricultural or community use. With the liner in place, a shallow, artificial aquifer is created de facto. This approach to the capture and shallow storage of water is of special value to the U.S. Southwest where scarce rains routinely sink deeply into the parched earth and, for all practical purposes, are lost. In another special water storage scenario, an in situ liner encapsulation zone with a pore-space-optimized backfill can be used as a thermal storage reservoir to store hot or cold water. In this design, surface waters could be cogeneration or solar heated, or renewably chilled (solar collectors run in reverse to capture and store renewable cold commodities), and stored for use in district heating and cooling schemes.

CONCLUSIONS

In situ liner elements, constructed by drill-split mechanical excavation and impermeable compound backfilling, are postulated to be solutions to environmental problems and are applicable to (1) AMD control by vein remining and replacement, (2) vertical landfilling, (3) deep burial of toxic solid wastes, (4) plume diversion of contaminated groundwater, (5) vat retention of contaminated groundwater (with an in situ treatment option), (6) underground storage of noxious liquids, (7) underground storage of compressed gases, and (8) the creation of shallow aquifers and artificial wetlands.

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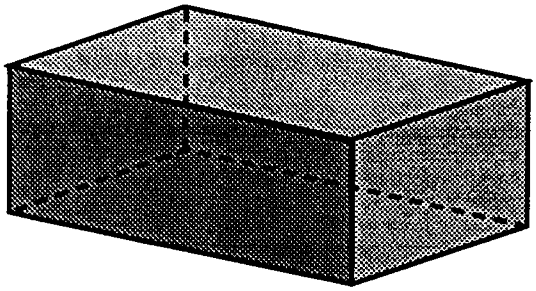
3. Lombardi, J. A., and C. V. Jude. Mechanical Excavation Systems (In Three Parts). 2. Stope Leach and Stope Autoclave Mineral Recovery Systems. USBM IC 9420, 1995, 28 pp.

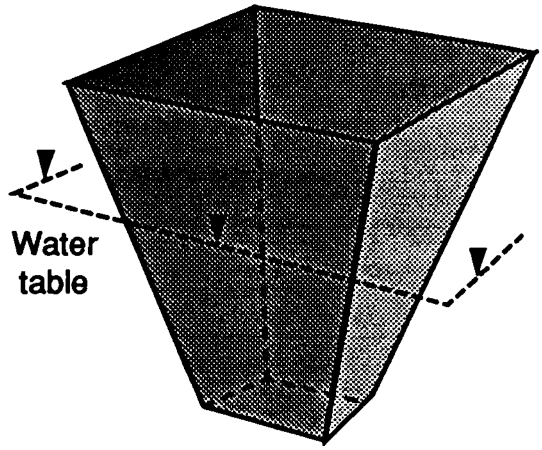
4. Chadwick, J. (ed.) Longwall to Save Landfill Time-Bomb. Min. Mag., June 1992, pp. 340-341.

5. Camm, T. W. Simplified Cost Models for Prefeasibility Mineral Evaluations. USBM IC 9298, 1991, 35 pp.

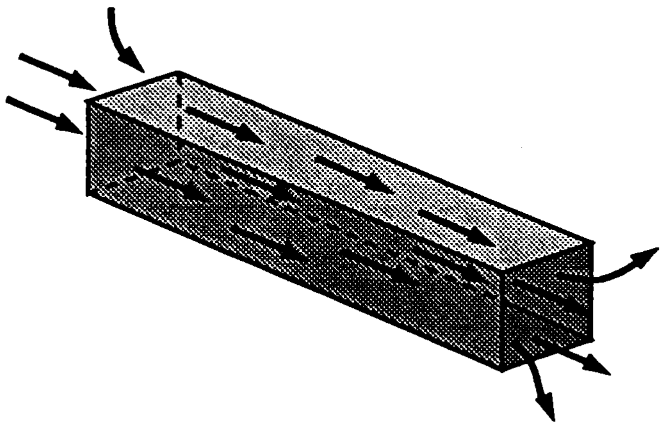
Figure 1



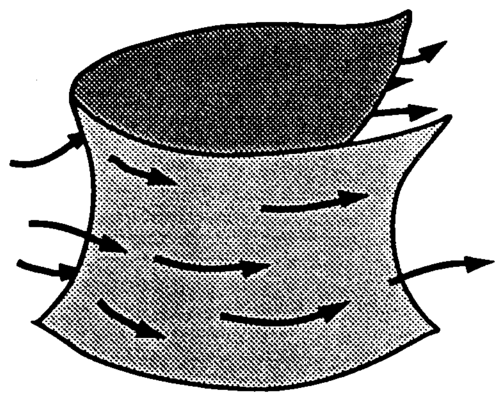
ENCAPSULATED VOLUME
Impermeable walls - 6 sides:
isolation cell



CATCHMENT
Impermeable walls - 5 sides:
retention basin or cofferdam



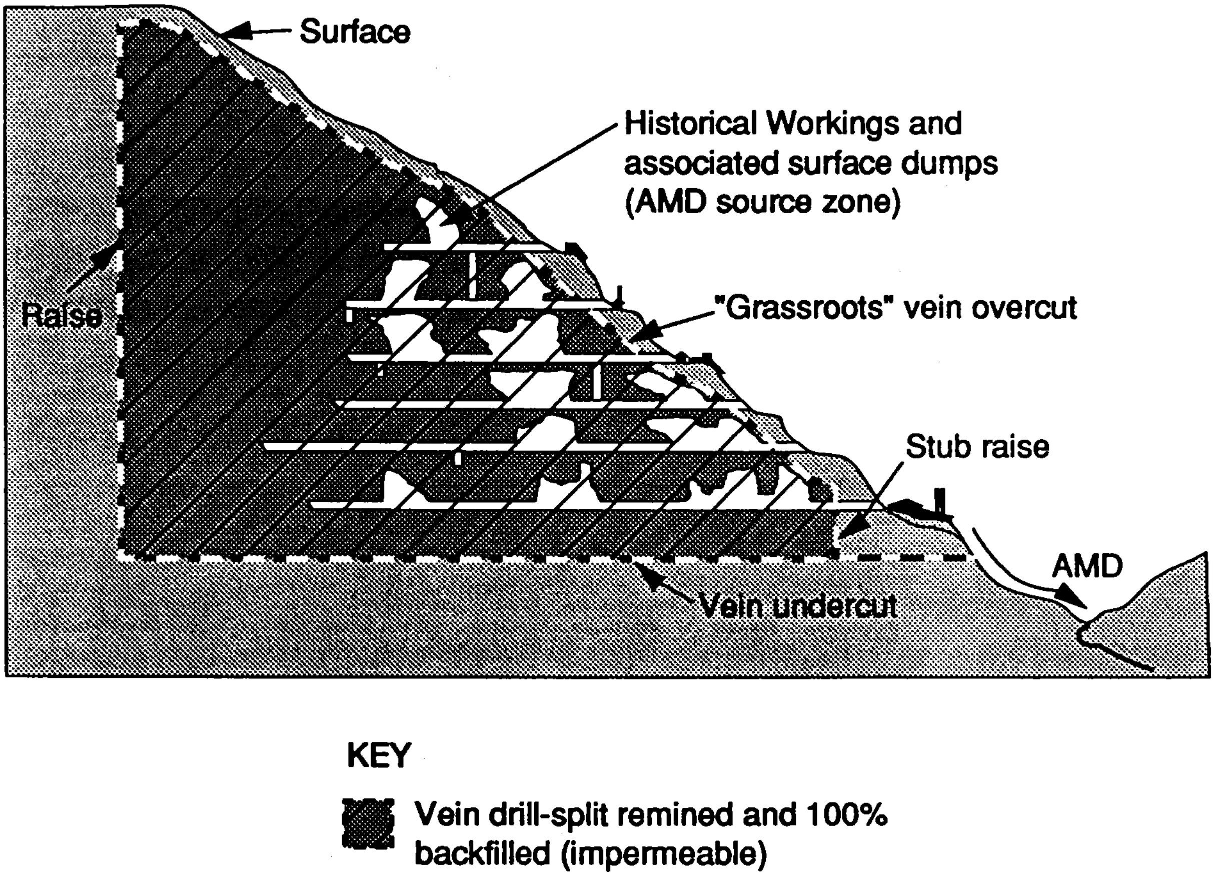
OPEN-ENDED FLOW CHANNEL
Impermeable walls - 4 sides:
Packed bed flowthrough



FLOW DIVERTER
Impermeable walls - 3 sides or fewer:
aquifer shunt or meteoric flow umbrella

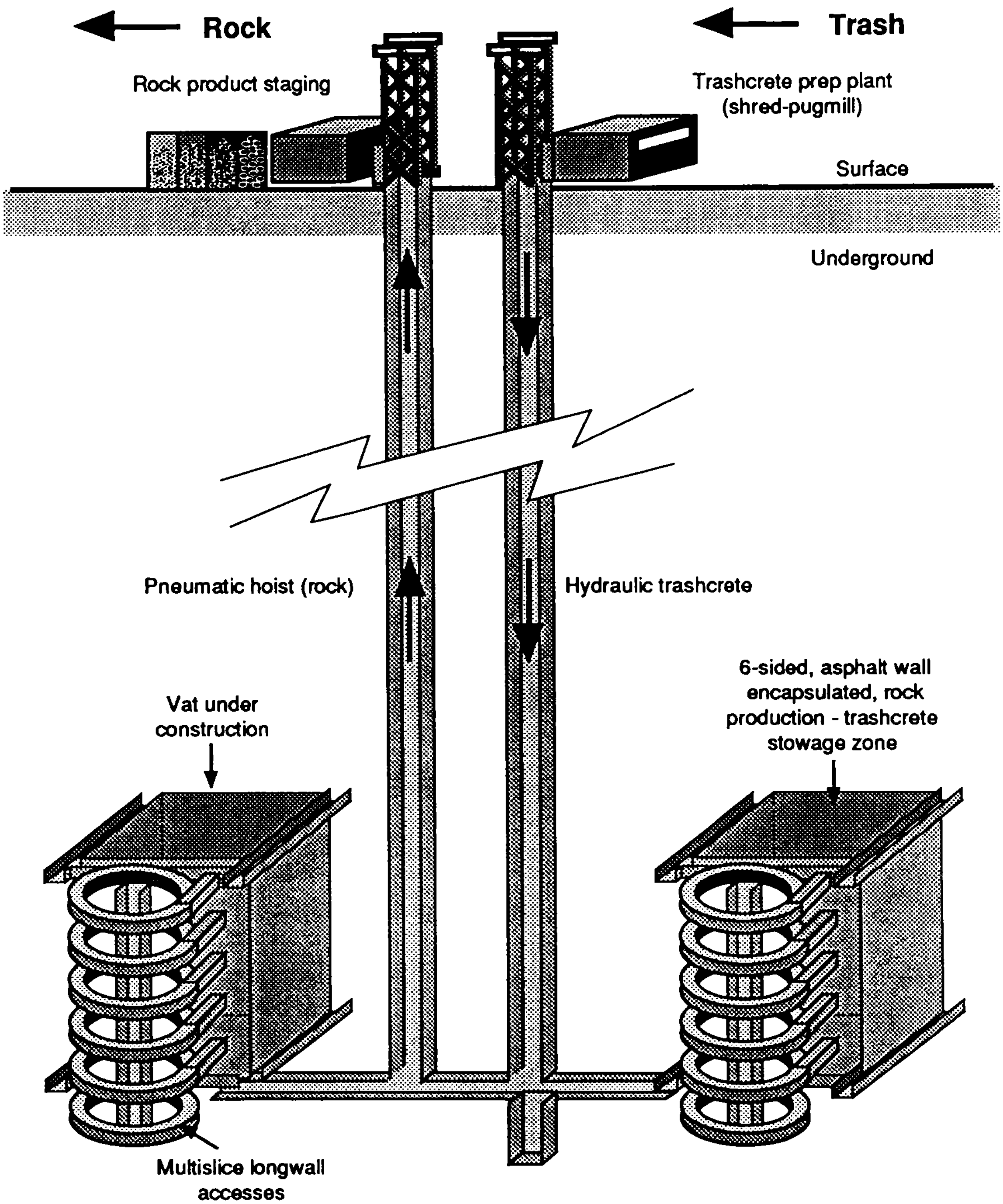
In situ liner construction forms and generic use designations.

Figure 2



Cross-section of AMD remediation of steeply dipping vein.

Figure 3



Schematic of a vertical landfill.

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