SECTION 10

SHRINKAGE METHODS

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10.1.1 INTRODUCTION

In shrinkage stoping the ore is generally mined in horizontal slices, starting from the bottom and advancing updip. The hangingwall and footwall are supported by broken ore left in the mined out stope. This broken ore serves as the working platform for airleg operators in the stope, and sufficient ore is drawn out at the bottom, following blasting, to provide suitable headroom for these operators.

Shrinkage stoping is applicable to the mining of steeply dipping orebodies where the orebody is competent enough to work under and the walls are sufficiently strong to be self supporting.

Rock bulks and increases in volume by 30 to 40% due to blasting. Approximately 30 to 40% of the blasted ore must therefore be drawn off following blasting in order to re-establish a suitable working space above the blasted ore. When the stope reaches it's upper limit the remaining 60% of the broken ore is recovered.

Broken ore is drawn off at the lower elevation from either drawpoint cross-cuts, using boggers (LHDs), rocker-shovels or scraper (slushers), or from ore-drive chutes. Both cross-cuts and chutes have to be closely spaced to facilitate even ore drawdown. Air powered scrapers can be used in the stope to level off the broken ore.

Shrinkage mining was a common stoping method prior to mechanised mining and the introduction of hydraulic fill. Sub-level stoping, cut and fill mining and sub-level caving have generally replaced shrinkage mining in Australia, Europe and Canada. The method is still used in a handful of non-mechanised mines in South America, Africa, Asia and Canada.

10.1.1.1 Disadvantages

The method is labour intensive and requires experience in such methods. The working conditions can also be difficult and relatively hazardous due to the fact that the broken ore is used as a working platform and has to be drawn down daily. Voids, uneven drawdowns and hang-ups can also cause problems.

The method is also a relatively low productivity method and the majority of the ore remains in the stope for extended periods of time. This has a major impact during the initial production phase of a mine – nearly 3 times as much ore has to broken than drawn in order to achieve full production. There is also a risk of over-drawing stopes, which leads to stope drilling difficulties and a requirement for timber platform construction.

10.1.2.1 Advantages

Shrinkage mining still remains, however, a mining method that can be implemented and practised with minimal capital investment in equipment and fill. The method requires the least capital investment and can be operated with small crews.

10.2.1 APPLICABILITY

Shrinkage mining is applicable for orebodies with;

1. Steep dips
2. Firm competent ore (operators working underneath backs)
3. Comparatively stable hangingwall and footwall
4. Regular ore boundaries
5. Ore that is not affected by storage in the stopes (oxidisation, cementation, combustion)
6. Orebody width from 1m to 12m
7. Low to moderate stress

10.2.1.1 Orebody Dip

The method is suitable to very steep orebodies, greater than 70° generally, and definitely exceeding the angle of repose (i.e. greater than 45°). This is required due to a few problems with orebodies at lower dip angles;

- Uneven and difficult daily draw-downs
- Hang-ups during final drawdown
- Hangingwall failures

10.2.2.1 Orebody Competence

The following estimates of applicable Rock Mass Quality (Q) are based on personal experience. Most shrinkage operations pre-date the established rock mass classification methods.

Shrinkage mining is applicable for orebodies with good ground conditions (Q>10), generally only requiring spot bolting. Any additional mesh or extensive bolting will tend to reduce productivity and could lead to draw problems and hang-ups.

The orebody should be sufficiently competent to be safe to mine without mesh and without excessive bolting. Mesh and bolts in the blasted ore adversely affect the flow of drawdowns. This requirement alone would make it difficult to implement shrinkage mining as a method for Western Australia, without daily geotechnical assessments.

10.2.3.1 Hangingwall and Footwall Competence

The rock mass quality of the hangingwall and footwall rock masses should also be at least fair (Q>4). Poor quality walls tend to unravel during drawdown of broken ore.
The hangingwall and footwall rock masses are only supported in most shrinkage mines by the broken ore. This support is minor, and once the stope is finished and being drawn down there is no support on the walls. The hangingwall and footwall rock masses both have to be competent for shrinkage stoping. Large equipment for drilling long cable reinforcement holes is unsuitable for the stopes and internal reinforcement is usually limited to short bolts, holes drilled with airlegs and bolts manually installed. Pillars can be left in shrinkage stopes, but they can have a major impact on the flow of broken ore and therefore have to be designed to minimise this impact.

Short split sets and grouted bars can be used for local wall support, and the plates or bolts are also designed to facilitate the attachment of safety chains for the operators.

10.2.4.1 Orebody Geometry

Due to the required flow of broken ore within the stoped out void, and the difficulty in installing reinforcement and leaving pillars, the orebodies should have reasonably regular ore boundaries and widths.

Stability problems can be associated with changing stoping widths and variable strike orientations. Pillars are usually the major stabilising option as cable bolt reinforcing is difficult to install in these limited working spaces (Plate 1).

10.2.5.1 Broken Ore Deterioration

The orebody should be stable following blasting, with no oxidisation, or other physical or chemical deterioration or alteration that could result in combustion or the cementing together of the rock mass.

High sulphur contents and partially weathered orebodies would have to be tested to determine their susceptibility to combustion and cementing. The clay content of shear zones could also have a detrimental impact on the flow of broken ore.

Cementing of the ore leads to great difficulty in extracting the broken ore, especially the ore sitting above pillars (between the chutes or drawpoint cross-cuts).

10.2.6.1 Orebody Width

Shrinkage mining can generally be used for orebody widths from 1m to 12m.

The minimum stoping width is only limited to that required for drilling operations. The hangingwall and footwall of wider orebodies can also be stabilised using internal pillars.

Orebodies wider than 12m can be mined using a transverse shrinkage method, but this requires pillars being left between adjacent stopes.

10.2.7.1 Stress

Shrinkage mining is only applicable in low to moderately stressed sections. High stresses can lead to stress fracturing in the backs which will require more support, reduced productivity and increased risk of hang-ups due to mesh and bolts in the broken ore. Stress related stope closure also leads to ‘pinching’ of the broken ore and subsequent difficulties during drawdown.

10.3.1 DEVELOPMENT

The two main shrinkage options include ore drive rail cleaning using chutes (the standard shrinkage method) and drawpoint cross-cut cleaning using boggers or rocker shovels.

The development strategy for the two main options are covered below, including

- ore drive rail cleaning with finger rises, cones and chutes and
- bogger (LHD) cleaning from drawpoint cross-cuts

Access for men, materials, services and ventilation is generally from the lower level unless previously established level is present above the stope. One of the advantages of shrinkage stoping is that stopes can be mined without any top access. The rises developed at either end of the proposed stope are usually timber lined and suffer moderate to severe deformation as the broken ore takes load and is drawn down.

10.3.1.1 Ore Drive Method

Typical development for shrinkage stoping using chute and ore drive rail cleaning through finger rises and cones (Figures 1 and 2) consists of;

Ore-driving along the orebody
Rising at both ends of the proposed stope to upper level
Sub-drive developed 5m above the ore drive
Finger rises developed from the ore drive to the sub-drive
Finger rises stripped to form cones

Construction of ore chutes
Construction of timber barricades at access rises
Commencement of stope blasting

10.3.2.1 Drawpoint Cross-cut Method

Development for trackless shrinkage stoping, using boggers (or rocker shovels) and drawpoint cross-cuts (Figures 3 and 4) consists of;

Development of footwall drive or decline
Cross-cut access to one end of proposed stope
Undercut or complete bottom slice of the stope
Cross-cuts from footwall drive to bottom of proposed stope
Two end rises, from the end cross-cuts up to the main level above, to provide access and ventilation to the stope
Commencement of stope blasting

The main advantages of the drawpoint cross-cut method are the reduced internal development (no finger rises, sub-drives or cones) and the removal of the requirement to leave pillars. The main disadvantage is the necessity for a footwall drive.

10.4.1 PRODUCTION RATES

Drilling and blasting of ore are carried out as overhead stoping, with the rough pile of broken ore in the stope preventing the use of mechanised drilling equipment. Standard practice is to use airleg rockdrills (or stoper drills), and 1.8 - 2.4m, 32mm holes, drilled up at an angle of 70° (from horizontal).

Production is therefore limited to the capabilities of short hole, airleg blasting except in the case of Alimak and longhole shrinkage.

Expected production (tonnage to be drawn) could range from 40 to 70 tonnes per shift per crew (2 airleg drills, 2 operators, 1 assistant). This tonnage would be available for drawing after the blasting of 115 to 200 tonnes per shift.

For an established mine with stopes in all stages of production (preparation, stoping and drawdown) the tonnage rate to consider for production purposes is the tonnage blasted. For new shrinkage operations where no stopes have reached the drawdown stage, however, the tonnage to consider is the available tonnage for drawing, i.e. 35% of the blasted tonnage. This can have a critical effect on the mill tonnage and early revenue.

10.5.1 EQUIPMENT

One of the main advantages of shrinkage mining is that equipment requirements are minimal. Airleg or stoping machines are required for drilling the ore, and haulage equipment is required to draw off broken ore on the haulage level (hand pushed side tipping cars as a minimum).

Longhole drilling equipment can be used for longhole shrinkage, and large boggers for the drawpoint cleaning methods.

10.6.1 ORE REMOVAL

The traditional ore handling system in shrinkage stoping entails direct dumping into rail cars from chutes below finger raises. Shovel loaders and boggers (LHDs) are more effective in conjunction with drawpoint loading systems, and can lead to far greater productivity.

Alternatives include scraper (slusher) cleaning from drawpoints, and finger rises and chutes loading direct into footwall drive loco trucks.

10.6.1.1 Chutes/Rail Cleaning

The traditional shrinkage method incorporates an ore drive on the lower elevation serviced by rail locomotives, and chutes drawing broken ore via finger rises and cones. The chute design and construction is dependent on the planned tonnage, life and the expected frequency of secondary blasting (steel chutes more blast resistant than timber). The steel chutes with higher tonnage capacities and lifespans involve far higher capital expenditure than timber chutes. All types of chutes are relatively labour intensive to construct and require experienced and skilled construction crews.

10.6.2.1 Drawpoint Cleaning

Drawpoint cleaning using rail based rocker shovels or boggers (LHDs) can be more productive than chute/rail/ore drive cleaning. Rocker shovels would generally load directly into rail cars, and boggers into trucks, rail cars or ore passes. Drawpoint cross-cuts are more suited to coping with larger rocks from wall slabbing or poor fragmentation.

10.6.3.1 Operational Guidelines

Shrinkage mining relies on there being a working surface of broken ore within reach of the stope backs. The tonnage of ore drawn off at the bottom must therefore be closely controlled. This requires;

- numbers of drilled production holes (and length, diameter and patterns)
- stope tonnages blasted
- area of stope face blasted (relative to drawpoints)
- drawpoints to draw
- tonnage to draw per drawpoint (related to blasted tonnage)

Local draw characteristics will be determined from historical data. This will indicate whether the material has a tendency to ‘bell’ out or ‘pipe’. Draw ellipses from previous performance should assist in determining which drawpoints should be used for blasting in certain sections of the stope.

Drawing of broken ore in a shrinkage stope can result in internal hang-ups and voids not visible either from the drawpoints or stope face. Safety chains should be worn by operators standing on the broken ore. The safety chains should be attached to a length of chain or wire rope suspended from rockbolts along either the hangingwall or footwall (or both).

10.7.1 SUPPORT and REINFORCEMENT

Shrinkage mining is suited to generally good ground conditions and intensive ground support is not normally required.

10.7.1.1 Stope Backs

Stope back support would only be required locally in areas of poor ground. The support should include bolts with an immediate work capacity, such as split sets and mechanical rockbolts. Where mesh is required it should be light gauge, sufficient only to support local scats, and light enough to be carried by hand and to be deformable in the broken ore.

10.7.2.1 Hangingwall and Footwall

Hangingwall and footwall support would tend to incorporate bolts for control of slabbing and dilution during drawdown. Split sets, mechanical bolts or grouted bars can all be used, dependent on the immediate rock quality and whether the rock around the collars is liable to fritter/unravel. The plates or bolts in the hangingwall and footwall should generally have a loop attachment for the fastening of safety chains (Plate 2).

Reinforcing using cable bolts is not normally used in shrinkage stopes due to limited access for longhole equipment. Pneumatic longhole equipment can be carried by hand into the stopes, or dragged using air winches, if cable bolts are required, and will cause significant production delays.

10.8.1 VARIATIONS

Shrinkage mining is a flexible method and there are many variations to the basic layout.

10.8.1.1 Rolling Shrinkage

Rolling shrinkage is a semi-breast modification of shrinkage where an overhand face advances on strike at an angle approximately equal to the rill angle of broken ore (see Figure 5). The operators use the broken ore as the working surface for drilling the face. The broken ore can be bogged as a follow on operation, to minimise the tonnage of ore maintained within the stope. Waste can also be tipped into stope as a follow on operation.

The main requirement for this method is top access, with the strike length of ore at the top of the stope governed by the spacing of top access rises.

10.8.2.1 Semi Shrinkage

The main economic disadvantage of shrinkage mining over other methods is the 60 to 70% of ore which has to remain in the stope void until completion of the stope. This can be reduced to 30% by the use of timber sprags and barricades installed at intervals up the stope. These barricades permit the release of broken ore away from the face, leaving only the uppermost barricades, holding up the ore required as a working platform.

This method is generally only feasible for stoping widths less than 2m.

10.8.3.1 Cut and fill shrinkage

Cut and fill mining can be operated as a pseudo-shrinkage method when there is a shortage of fill. The broken ore is only bogged and levelled until the required working height is achieved. The broken ore builds up until either fill becomes available or the stope reaches its' planned upper elevation. The broken ore is then cleaned from cross-cuts using remote boggers. The exposed height of the hangingwall and footwall during the final drawdown can lead to failure and dilution. If use of this method is anticipated in advance, cable reinforcement could be installed to reduce wall failure and dilution.

10.8.4.1 Longhole Shrinkage

Longhole shrinkage is a method combining bench stoping and shrinkage. The broken ore is not used as a working surface, however, and is only left in the stope to provide support to the hangingwall and footwall surfaces (Figure 6). This method can produce at far higher tonnages than standard airleg shrinkage stopes, but there is an increased risk of dilution due to hangingwall damage from hole deviation and poor blast timing.

10.8.5.1 Alimak Shrinkage

Alimak shrinkage is still used by specialised contractors in Canada. Alimak rises are developed on ore between levels and the platforms used for long horizontal blastholes. The broken ore is not used as a working surface, however, only to provide limited support to the hangingwall and footwall.

10.8.6.1 Transverse Shrinkage

Transverse shrinkage can be used (as with transverse cut and fill mining) to mine wide orebodies. Stopes are aligned across the orebody and pillars are left between adjacent shrinkage stopes. The pillars can be either permanent or can be extracted at a later stage using a longhole method (after filling of the shrink stope void), or underhand cut and fill.

10.9.1 REFERENCES

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Shrinkage Stoping

Hangingwall Failure

NTS | Drawn: MHT | Date : 26.04.00 | Plate : 1

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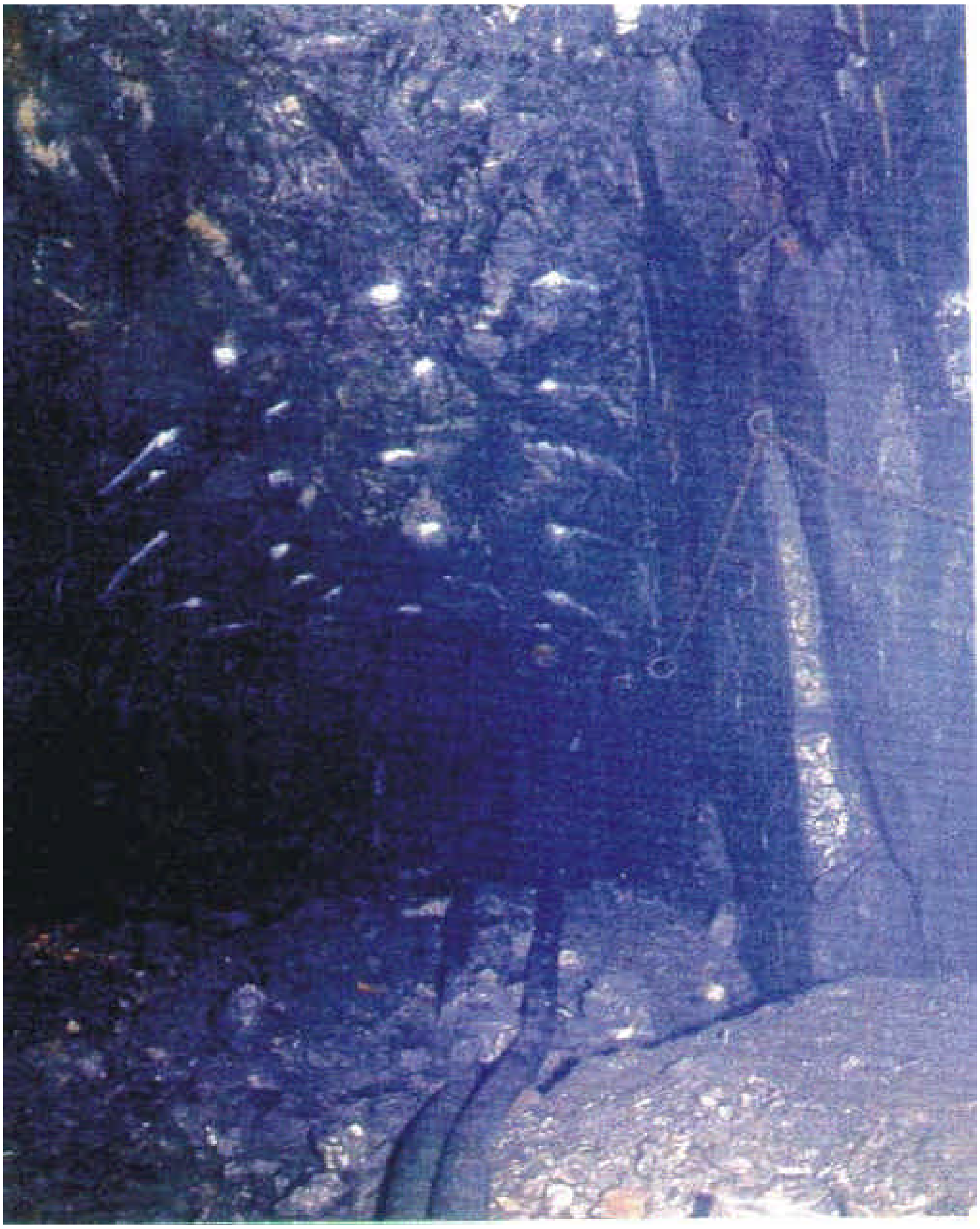

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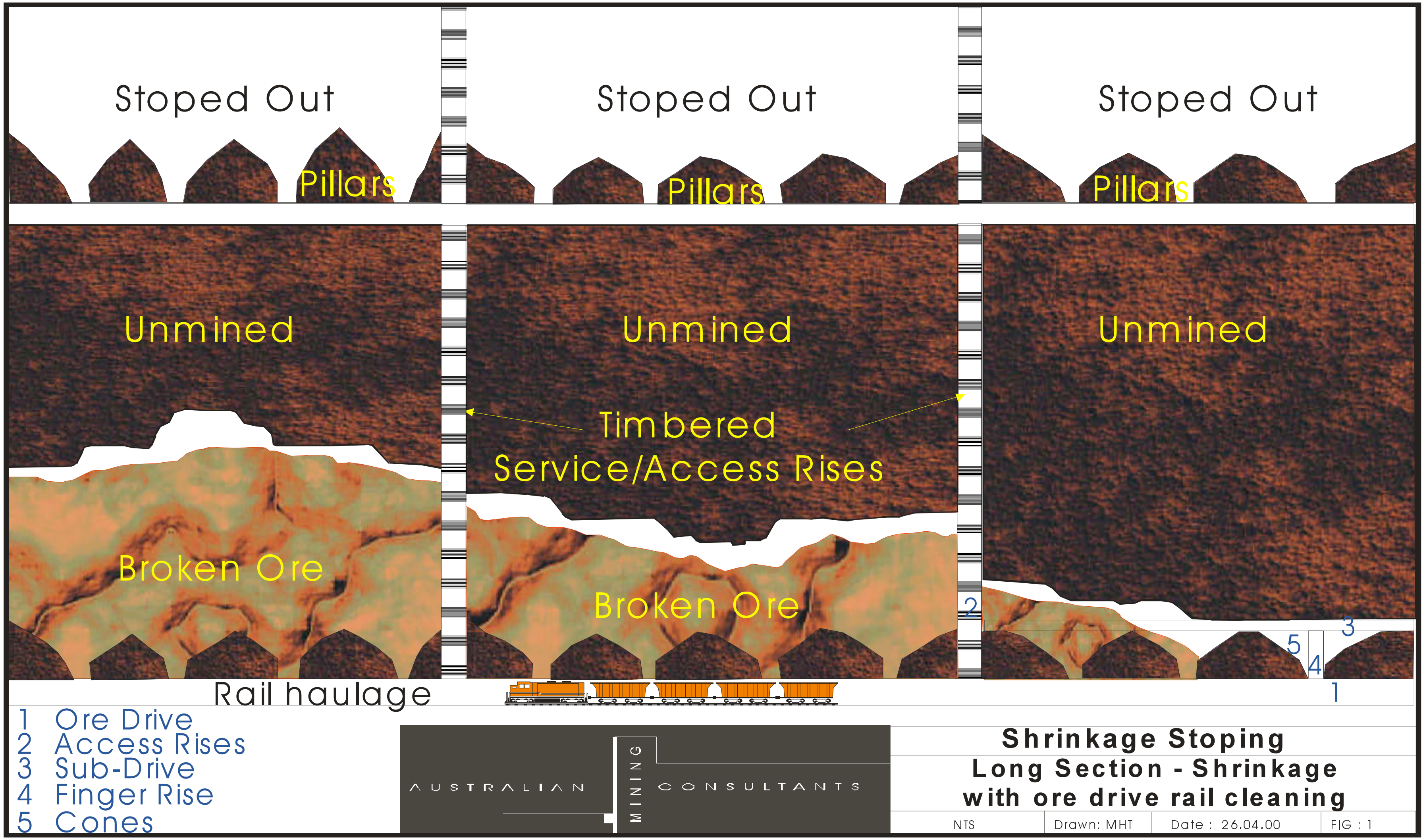
Shrinkage Stoping

Hangingwall Support, Hole Mark-up and Safety Chains

NTS	Drawn: MHT	Date : 26.04.00	Plate : 2


Stoped Out
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Pillars
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Unmined
Unmined
Unmined
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Service/Access Rises
Broken Ore
Broken Ore
2
3
5
4
1
Rail haulage
1 Ore Drive
2 Access Rises
3 Sub-Drive
4 Finger Rise
5 Cones
AUSTRALIAN MINING CONSULTANTS
Shrinkage Stoping
Long Section - Shrinkage
with ore drive rail cleaning
NTS
Drawn: MHT
Date : 26.04.00
FIG : 1

Figure 1; Isometric view of Rail/Chute/Ore Drive Shrinkage Stoping

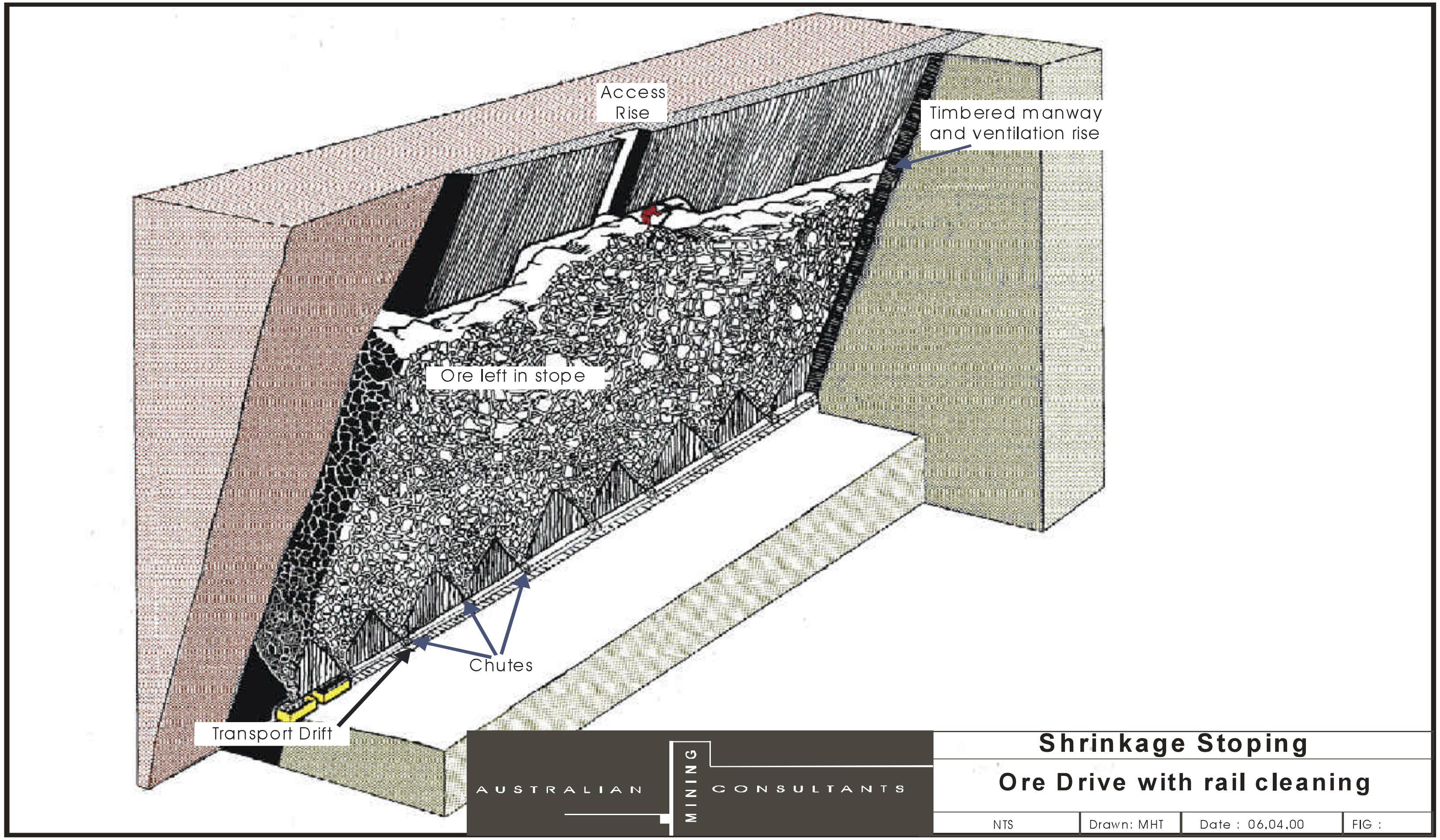

Figure 2; Isometric view of Rail/Drawpoint Cross-cut Shrinkage Stoping

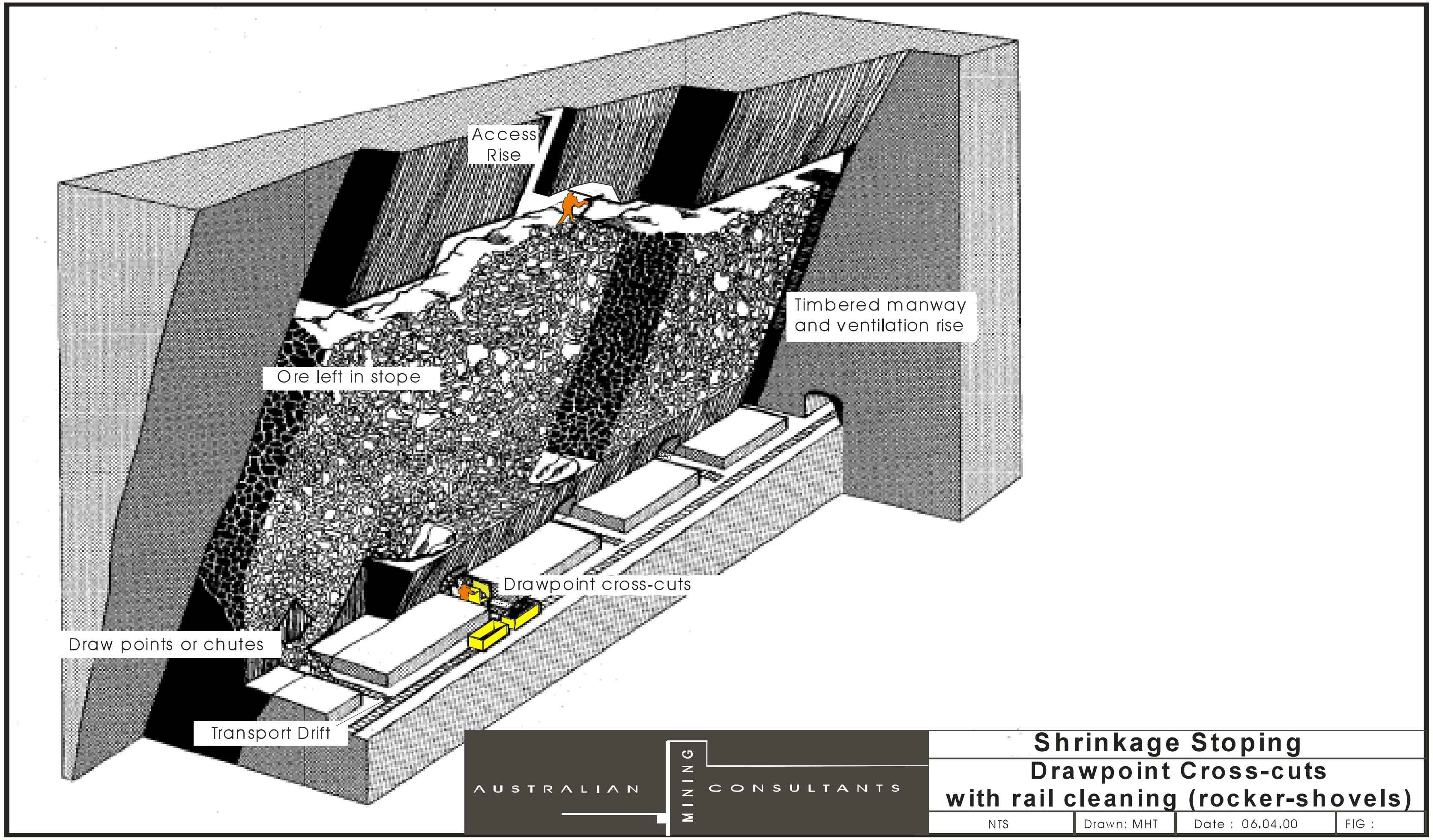

Figure 3; **Isometric view of LHD/Drawpoint Cross-cut Shrinkage Stoping**

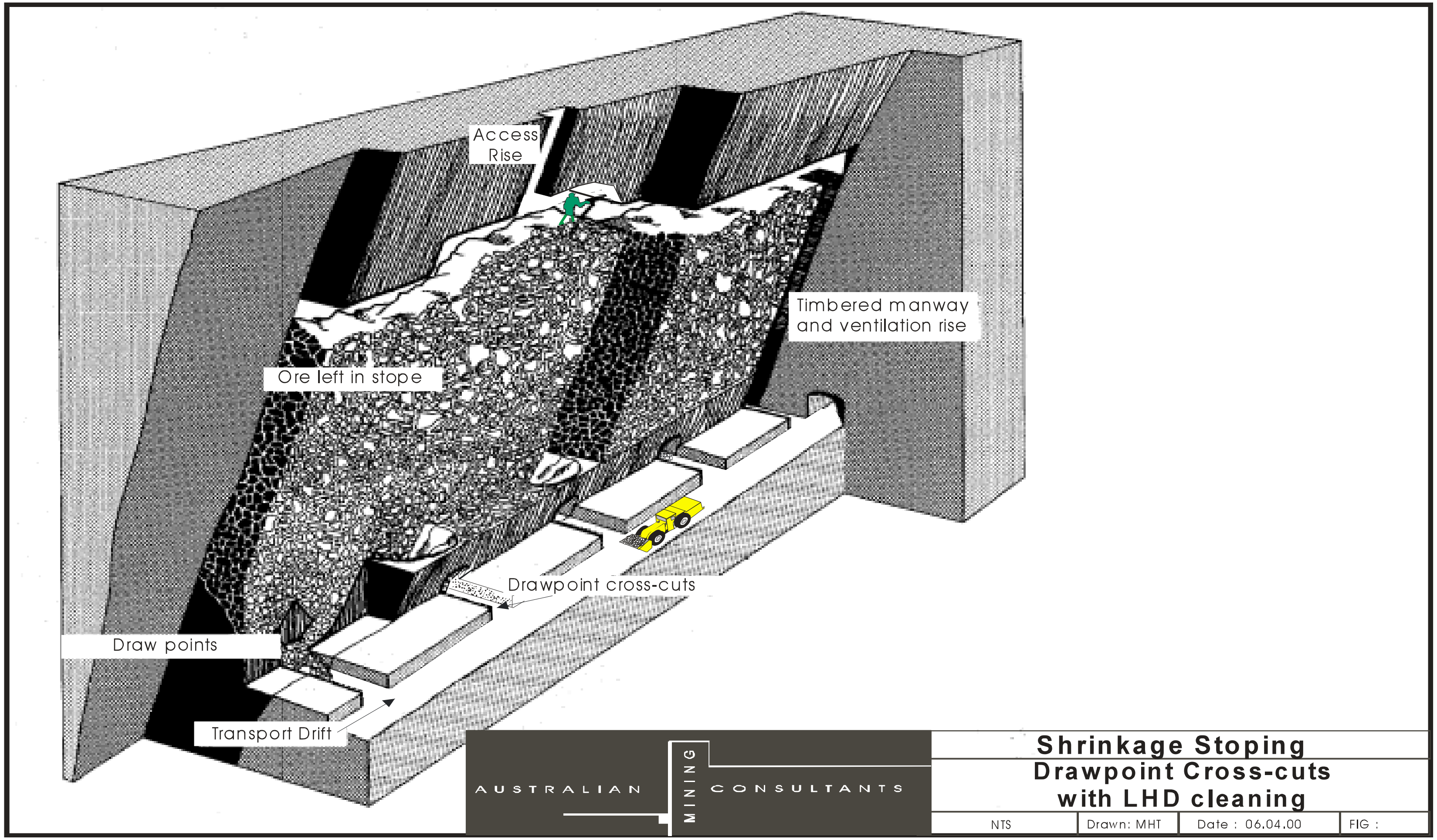

Figure 4; Isometric view of Rail/Chute/Ore Drive Rolling Pile Shrinkage Stoping

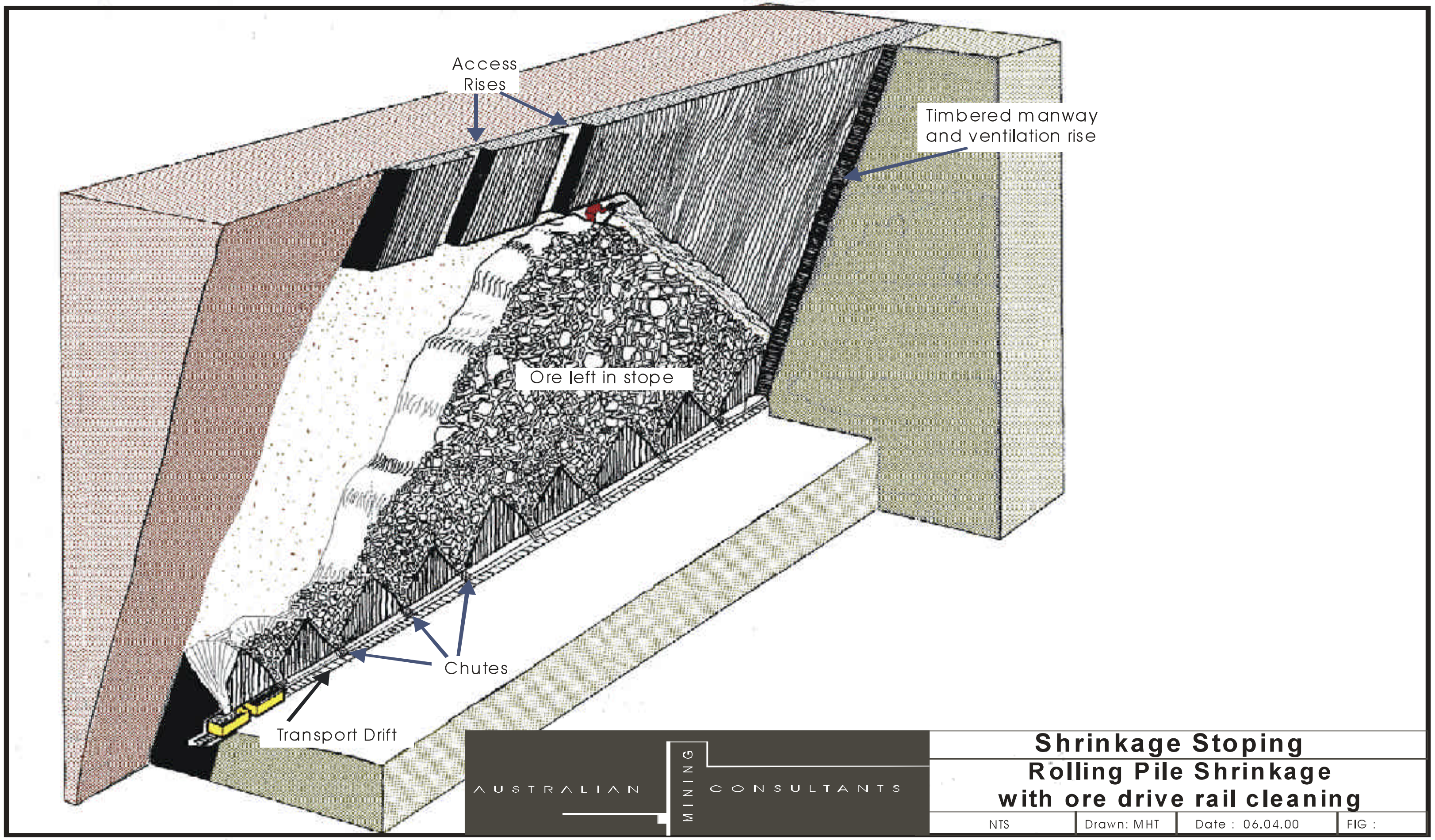

Figure 5; Long Section of Longhole Shrinkage Stoping