Mining Evaluation of a Low Grade Uranium Mineral Resource

1 Introduction

Bingham Canyon (2005)

- ❑ Presentation attempts to shed some light on how the mining of a low grade uranium mineral resource might be evaluated
- ❑ A generic approach rather than a specific uranium has been adopted
- ❑ Radiation risk does not have to be all pervasive
- ❑ Deals only with the mining - not resource estimation or processing
- ❑ Surface mining has been restricted to hard rock open pit activities- not include solution or sand mining

1 Introduction Cont…

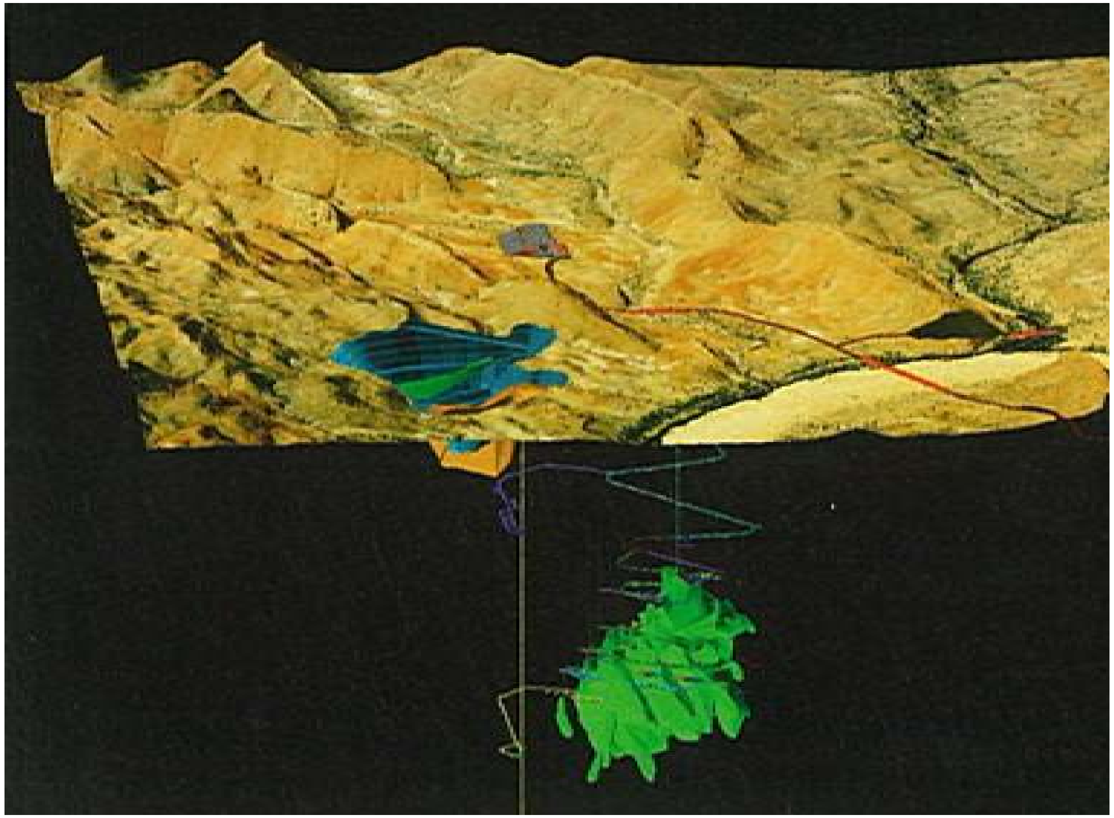
- Paper to consider
  - Part 1 **Selection of a Mining Method for a Uranium Mineral Resource**
    - Stages in a normal evaluation
    - Mining Method Selection
  - Part 2 **Mine Design for a Uranium Mineral Resource**
    - Mine design
    - Remediation
    - Risk
- Both parts are quite long but will be published on the IAEA web site

Part 2

Mine Design for a Uranium Resource

- Mine design
- Remediation
- Risk

Mine Design - General



Mine design is a sequential and frequently circuitous process.

- Broad brush assumptions are made followed by preparation of preliminary layout
- After the "Preliminary Layout", complementary studies are commenced that complement, support and enhance that layout to produce a basic mine plan

Mine Design – General Cont…

4 Mine Design - General

Firstly, two key decisions:

- Production rate
  - Why?
    - All cost parameters relate to production rates
  - Resource should determine production rate, not other external factors
  - Taylors rule is a starting point
    - Taylor's Rule **Annual Production Rate = $(\text{Resource})^{0.75}$ x 5**
    - Example - Resource of 5.0 million tonnes equates to production rate of 500,000 tonnes per annum

- Cut-Off Grades
  - Purpose
    - Defines economic material, ie ore
    - Potentially impacts on available resource size
  - The Economic Definition of Ore, Lane, F L, (1991)
  - Break Even
  - Marginal
  - Cut-off strategy - different cut-off for different processing – milling and heap leach
  - Cut-off grades relate to costs/production levels and need constant review as parameters change or are refined

5. Surface Mine Design

5.1 Surface Mine Design - Overview

The basic planning tools/requirements for a simple, initial evaluation of an open cut mine.

- Geological resource (including surface topography)
- General Mine Planning Software (GMP)
- Optimisation software
- Planning and optimisation input parameters
- Skilled practitioner(s)

Langer Heinrich

Open pit Mine Plan is achieved via:

- **Preparation of a Mining Resource**
- **The completion of an Optimisation exercise**
- **Design of the Open Pit Design and Scheduling**
- **Completion of Complementary Studies**

5. Surface Mine Design Cont…

5.2 Mining Resource:

- Not a Joint Ore Reserve Committee (JORC) term -
  - part way between resource and reserve
- Is a *massaging* of the geological resource to better represent what might be mined. For example
  - Removes blocks too small to be mined
  - Dilutes other areas to better reflect reality
- Completed in the GMP or manually on plans/sections

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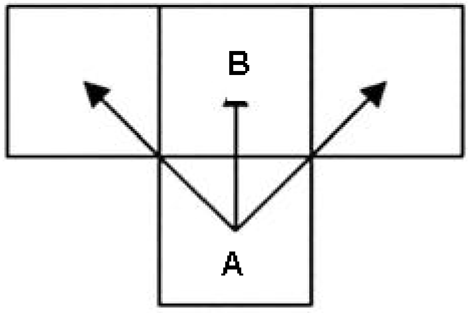
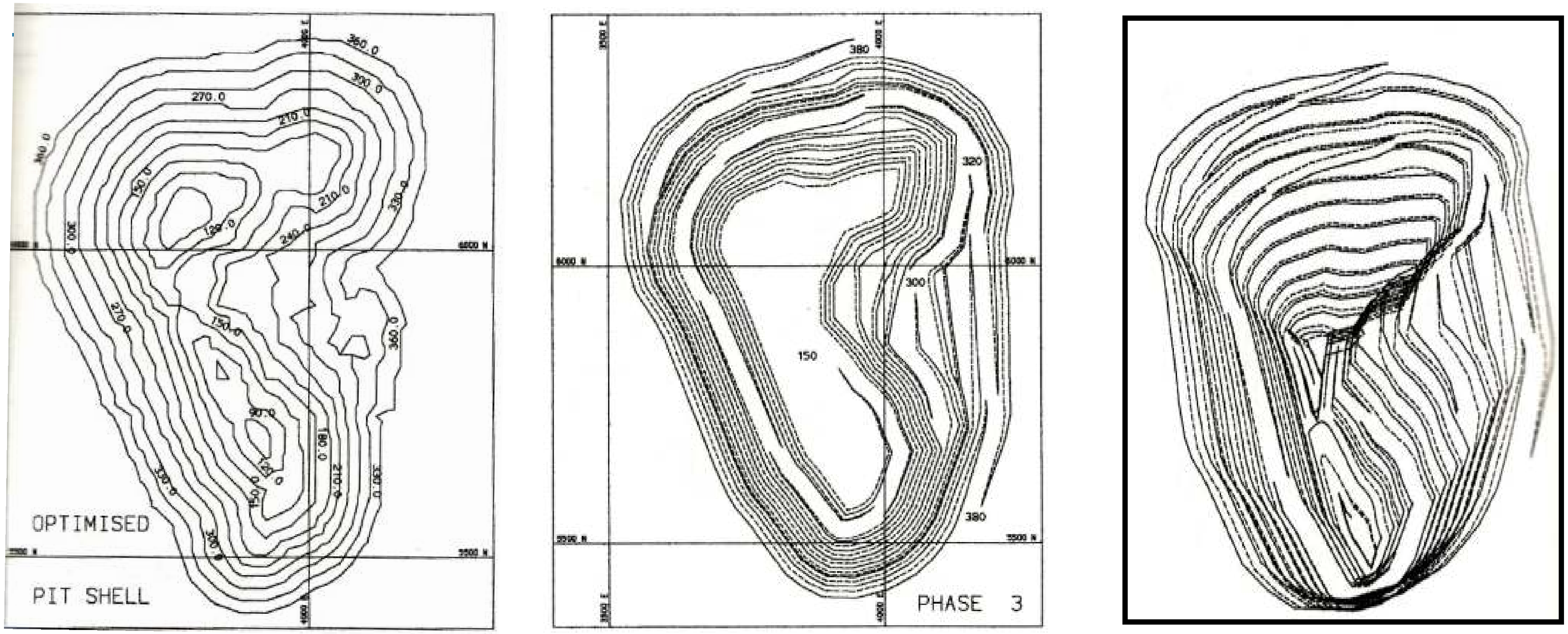
5.3 Optimisation



Structured Arc

- Optimisation Software
  - Lerchs Grossman algorithm (1964)
  - Has revolutionised open pit design.
  - Produces a pit shell, **not a designed pit**.
  - Shell can be output as a set of wall contours (strings)
  - Based on concept of structured arcs (to mine block A must mine block B but not necessarily the reverse)
- Input Parameters
  - Revenue estimates (inc statutory charges and royalties)
  - Metallurgical/processing recoveries
  - Site Operating cost estimates
  - Wall slope parameters (geotech model)
  - Assumptions on production rates
  - Mining operational parameters for NPV estimates (optional)

5.3 Optimisation Cont…



Optimisation Vs Designed Pit (Moddejongen, 1994)

5. Surface Mine Design Cont….

5.4 Pit design and scheduling

- Completed within General Mining Package (GMP)
- Designed pit must produce similar results to optimisation
- Start with simple pit and improve as necessary
    - Optimisation strings used as template
    - From top down or bottom up
    - Pit design functions are driven by haul road segments and pit base/top
- Scheduling
    - Continuity of ore to processing
    - Smooth out material movements
    - Test scheduling from optimisation

5.5 Complementary Studies

The following mining studies either complement, contribute to or are dependant on the pit design.

- Further Geotechnical/Hydrogeological
- Ore and Waste Dump Design
- Environmental
- Grade Control Requirements/Procedures
- Contractor vs Owner Operator
- Equipment Size and Selection
- Drill and Blast Procedures
- Radiation Management Plan
- Mining Ore Reserves
- Infrastructure
- Costing
- Manning
- Logistics

6. Underground Mine Design

6.1 Overview

Underground "Mine Plan" is produced from:

1. The preparation of a Mining resource
2. The development of a Mine production layout and sequence
3. The development of a Primary access and development layout
4. The development of Primary ventilation network
5. The completion of Complementary Studies

6.2 Mining resource and mining sequence

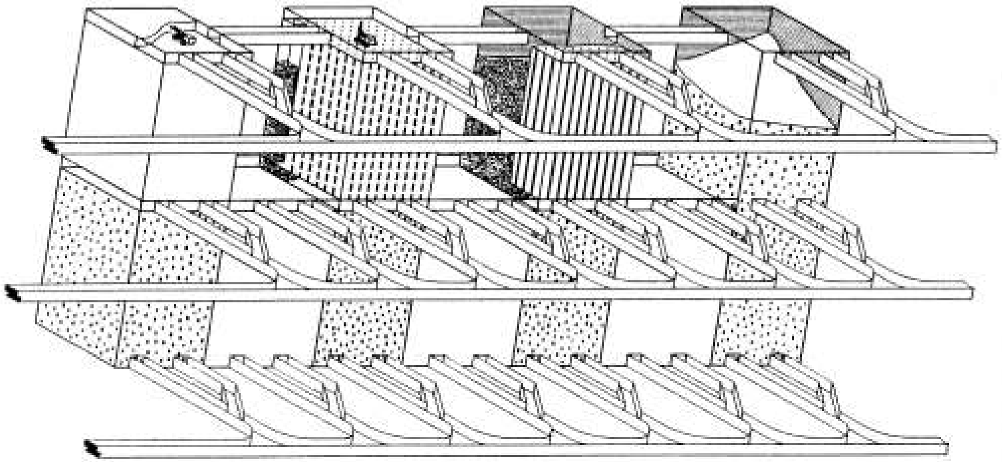
- Preparation of an underground mining resource is a two part process
  - *Massaging* of geological resource for minimum width etc as per open pit
    - Related to mining method
  - Identifying attractive mining areas from within a global resource
    - Identification is driven primarily by cut-off grades
    - Completed manually within GMP and/or via underground optimiser

6.3 Mining Production Layout and Sequence

- Production layout follows mining resource preparation
- Layout needs to consider geotechnical requirements for
  - stope dimensions
  - local pillar dimensions
  - Sublevels intervals
  - Extraction sequences
- Layout also needs to consider
  - Broad concepts on pillar recovery
  - General understanding of extraction sequence including likely effect on stress levels
  - General understanding of scheduling requirements
- Easier to match development to ore body than ore body to development
  - Existing development can make extraction layout more difficult

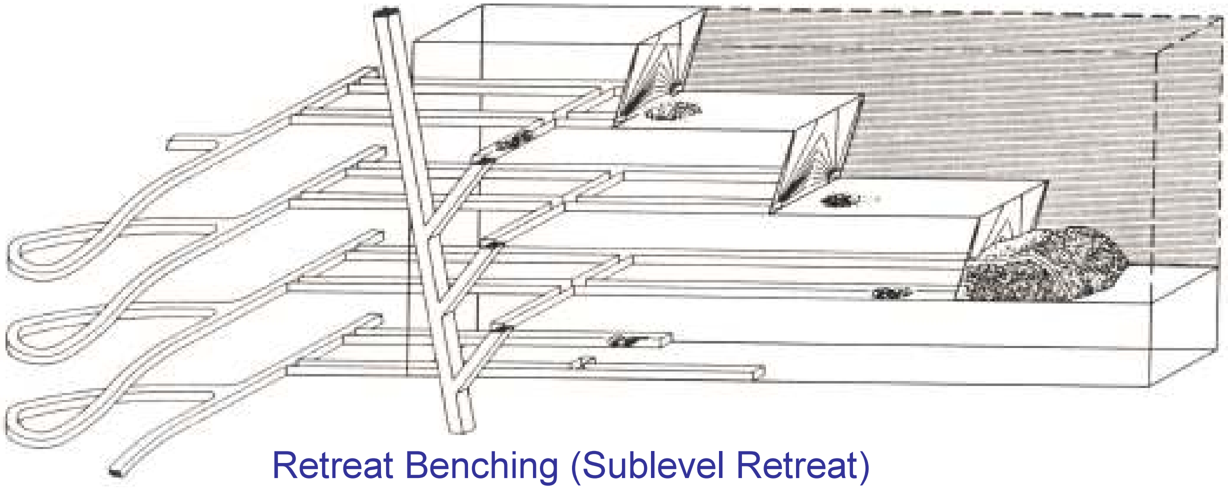
6. Underground Mine Design Cont….

6.3 Mining Production Layout and Sequence Cont...



Transverse Blasthole Open Stoping

Schematics of Open Stoping Methods (Potvin and Hudyma 2000)



Retreat Benching (Sublevel Retreat)

Issues

- Stope dimensions ?
  - Open Stope (20x20x40 = 50,000 tonnes)
  - Benching (10x150x15 = 67,000 tonnes)
- Sublevel intervals ?
- Pillar dimensions ?
- Extraction sequence ?

6. Underground Mine Design Cont….

Underground Optimiser

- Underground optimiser is a computer routine often contained within GMP software that is used to optimise the blocking out of underground mining resource
  - Open pit optimiser deals with individual blocks from a block model – each block is a stand alone economic entity

    BUT

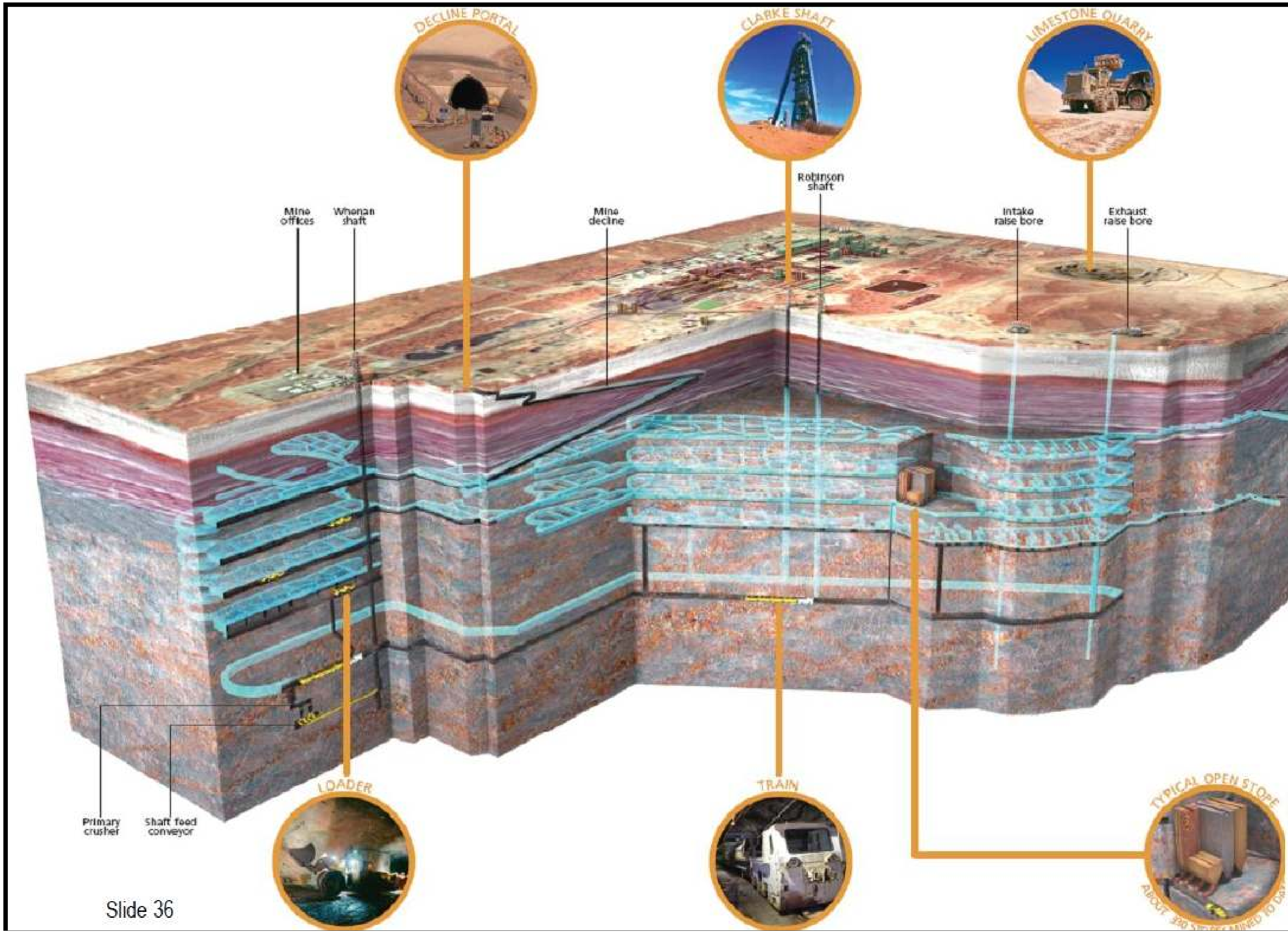
  - U/G must consider composite production areas not individual blocks
- U/G optimiser started with "Floating Stope" routine (1990s) – Passed a "floating stope" envelope over a resource trying to identify and optimise above cut-off material
- Current generation include Datamine's Mineable Shape Optimiser and Snowden's Stopesizer
- Do not have the "Gravitas as open pit optimisation but "they are working on it" (Alford, and Hall, 2009)

6.4 Mine access and primary orebody access

- Mine access is access from surface
- Orebody access is the link between the mine access and the orebody

- Need to consider material haulage **and** man and supply logistics
- Mine access and haulage options include
  - Shaft
  - Decline
  - Conveyor
  - Pumping
  - Combination of above
- Decision on main mine access must include decision on orebody access.
  - Used to be 100 foot spaced levels with rail haulage. Diesel trackless equipment revolutionised options
    - Decline access and internal ramps with trackless haulage
    - Shaft and conventional level with trackless or rail haulage
    - Shaft and internal decline/ramp access with trackless haulage
    - Decline access and conventional level with trackless haulage
    - Decline access and internal ramp for man and supply with one or more main trackless haulage levels to a haulage shaft
    - As above but utilising rail haulage on main haulage levels
    - As above for shafts but with conveyors
- Considerations include; Production rate, Mine life, Flexibility, Mining method.
- For economical, mass movement ore passes/rail is still very much an option (Olympic Dam)

6. Underground Mine Design Cont….



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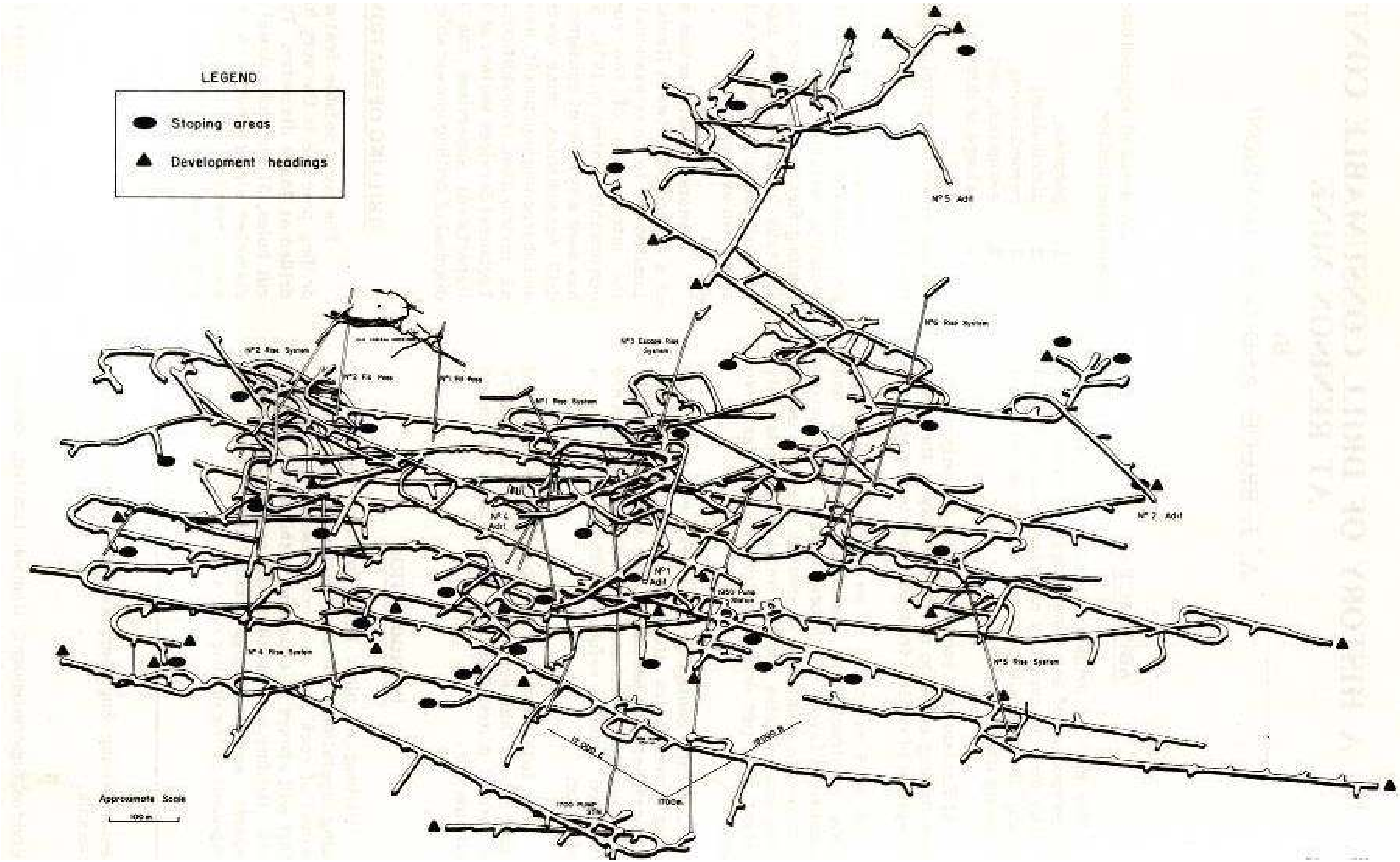
resourcing the future

6.4 Mine access and primary orebody access



Renison Mine-Isometric View of Underground development 1985 (Bruce and Davidson, 1985)

6.5 Primary ventilation network

- Primary network consists of the major exhaust and intake airways that control the total airflow
  - consists of the major exhaust and intake airways that determine the total airflow
  - involve longterm infrastructure and mine development
  - must exist harmoniously with the longterm mine plan and extraction sequence.
  - inadvertent damage from nearby mining can result in major mining interruptions

- Secondary Network involves the ventilation of individual stopes/production areas
  - Needs adequate, robust and flexible primary system

- Design starts
  - after primary production layout
  - with estimate of overall ventilation requirements based on
    - Production rates
    - Equipment levels
    - Radiation issues
    - Working areas

Primary ventilation network cont…

6.5 Primary ventilation network Cont…

Ventilation General

- Stope ventilation is usually flow through ventilation
- Sub level cave ventilation is forced
- Development ventilation is forced
- Ventilation requirements in non uranium mines based ultimately on air quality
- Uranium ventilation based on air quality and time
  - not as flexible
  - higher volumes required
- High grade uranium requires remote or un-manned techniques
- Low grade uranium requires
  - adequate ventilation
  - provision for dealing with random high radiation situation
  - Ventilation needs to consider radiation issues associated with mine drainage
  - Ventilation needs to be supplemented by hygiene regime

6. Underground Mine Design Cont….

6.6 Complementary Studies

The following mining studies complement, contribute to or are dependant on the preliminary mine layout

- Scheduling
- Further Geotechnical/Hydrogeological investigation
- Major Infrastructure Design
- Fill Requirements
- Development Procedures
- Operating Geology and Grade Control Procedures
- Drill and Blast Procedures
- Radiation Management Plan
- Contractor Vs Owner Operator
- Equipment selection
- Ventilation
- Mining Reserves
- Services (utilities) : power, pumping, service water, compressed air, communications
- Costing
- Manning
- Logistics

7 Remediation

7.1 General

- ❑ Addressing environmental issues, including remediation issues from day one is in a company's own self interest. It is not in a company's interest to exhaust a resource but be unable to leave site because of unresolved remediation issues.
- ❑ An immediate commitment to environmental issues
  - ➢ Establishes a company's credentials with both the community and authorities
    - ❖ **For the current project and for other projects**
  - ➢ Establishes an effective permitting process
  - ➢ Provides the opportunity to credibly obtain required baseline and sampling data including that required for remediation such as waste rock characterisation data
  - ➢ Provides the opportunity to embed an environmental culture within the company
  - ➢ Enables the most efficient and cost effective methods of remediation to be implemented.
  - ➢ Enables design to encompass agreed final landform and other remediation commitments without resource consuming *retro fitting*

For mining, primary (although not only) remediation considerations are:

- ❑ Waste Dumps
- ❑ Mine Drainage
- ❑ Mining Voids

7.2 Waste Dumps

- Mostly an open pit issue but not exclusively.
  - Waste dump remediation is now relative standard practice
  - Stockpiling of topsoil from pit and waste dump footprint stripping, for later use.
  - Face angles to be cut back from 37 degrees to 7-20 degrees
  - All exposed surfaces to be contoured for drainage control, top soiled and vegetated.
  - Material with undesirable characteristics to be encapsulated within the dump
  - Stability to be designed and constructed to accepted geotechnical standards .
  - Topsoil and/or seeding requirements dependent on the final landform/use
- Early remediation is:
  - Cost effective and efficient.
  - More importantly, failure to plan and start early is not cost effective resulting in
    - Poor top soil
    - Difficult dump faces
    - Failure to encapsulate problematical material

7.2 Waste Dumps Cont…

Concurrent reclamation of waste dump (Read and Stacey, 2009)

7.3 Drainage


Erosion due to poorly designed water-control structures

Evaluation and planning needs to consider drainage during and after operations

1. Drainage during operation
   - ➢ Can't avoid dirty/ contaminated drainage
     therefore
     - ❖ Need segregation of clean and dirty
     - ❖ Forward planning to minimise dirty reticulation
   - ➢ Would normally have a restriction of zero discharge for contaminated water
     therefore
     - ❖ Cleanup procedures/facilities required to permit discharge
     - ❖ Plan required to minimise requirement for discharge
2. Drainage after operation
   - ➢ Eliminate source of contamination by burying and/or sheeting and vegetating.
   - ➢ Cleanup and integrate old contaminated with old clean
   - ➢ Establishment of sustainable cleaning if required (eg wetlands)
   - ➢ Designing drainage networks that are suitable for purpose (flows, volumes, velocities)

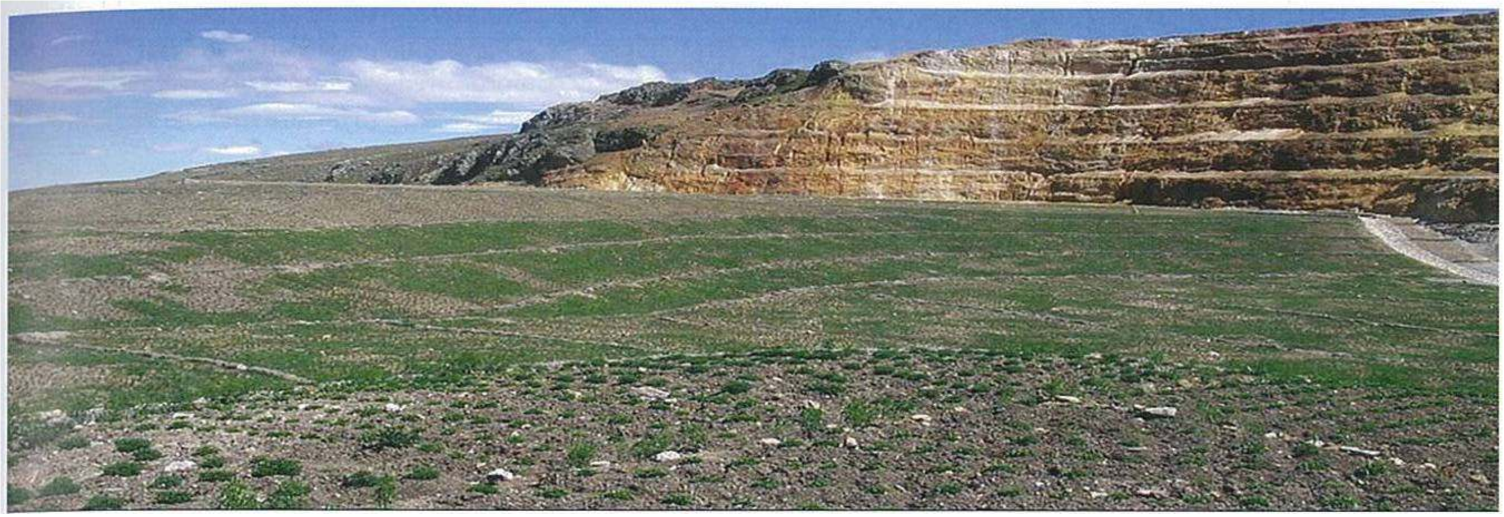
7.4 Mining Voids

- Dependent on required landform/ land use **and** community safety.
- Unlike dumps and drainage no generic remediation procedures

- Open Pit Considerations
  - Long term stability and wall angles
  - Requirement for full or partial backfilling
  - Management of water inflows and flooding in tropical/wet conditions
  - Management of fluctuating water table levels in arid conditions
  - Management of adverse water chemistry including radiation issues
  - Security to restrict accidental access of personnel and/or stock
- Underground Considerations
  - Not easily visible
    - Sudden collapse of inadequately supported workings
    - Obscured surface breakthroughs
  - Long term stability
    - Stopes
    - Cave
    - Workings open to surface
  - Water discharge and/or quality (as per open pit)

- Options available to small operations may not be available to large operations.
  - eg 100 metre pit Vs 500 metre pit with significant wall failure

7.4 Mining Voids Cont…



Backfilled pit showing reclaimed area (Read and Stacey, 2009)

Conclusion

- ❑ Collectively, these issues can be expected to have an impact on project economics
- ❑ Intent should be to minimise impact which must include inclusion in early planning and evaluation

8 Risk Assessment

8.1 General

Risk ***…the chance of something happening that will have an impact on objectives and is measured in terms of a combination of the consequences of an event and their likelihood (Standards Australia 2004)***

- Evaluation, design and operation is driven by
  - Risk identification and qualification

    followed by
  - Development and implementation of risk management systems

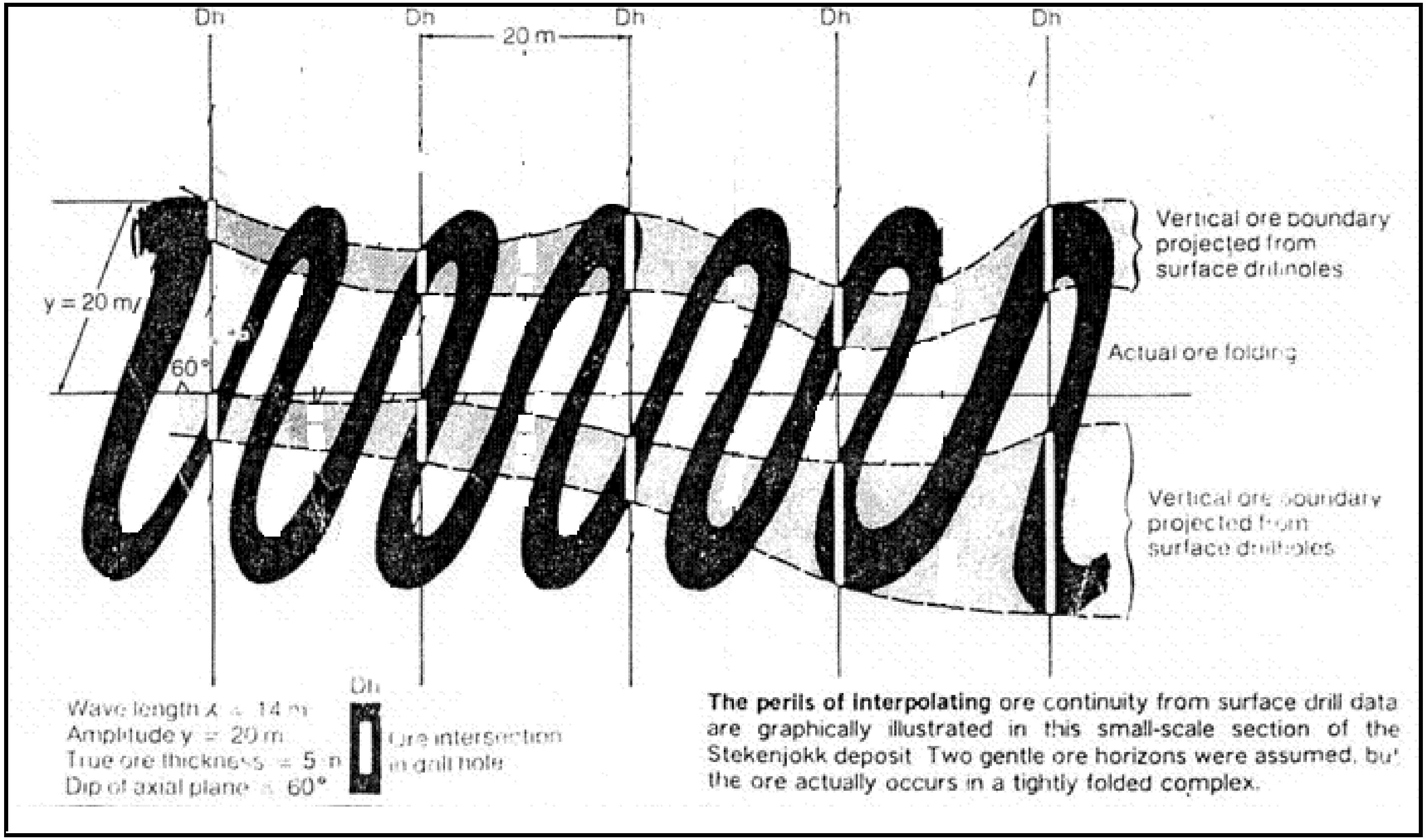
    (at least it should be)
- Positive as well as negative risk
- Two categories of risk in project evaluation
  1. Risks to completing the evaluation process on time and budget
  2. Risks of the evaluation achieving the correct outcomes - primary concern here
- Four main generic areas of mining evaluation technical risk
  1. Geological resource model
  2. Geotechnical/hydrogeological model
  3. Mining method selection
  4. Revenue assumptions

8.2 Geological Resource Models

- Failure of resource to provide "the goods" can result in financial impact - up to closure
- Incorrect structural interpretation can result in incorrect mining method or development location
  - Geology inputs are interpretations – not facts (*Berry, 2009*)
- Resources are non homogeneous rock masses, structurally and mineralogically
- Estimation is a balance between data density, data quality, cost and time.
- Need to consider the unknown unknowns (logging consistency) as well as the known unknowns (drilling density)
- Risks are recognised by industry
  - Purpose of JORC code categories of resources is to identify levels of confidence
  - Development of sophisticated geostatistics - improve estimation confidence
  - Range of Quality Assurance measures have evolved for exploration and resource preparation activities
- Resource evaluation *learning* usually continues well into the life of an operation. It is unlikely a resource will ever be completely understood before mining commenced

8.2 Geological Resource Models Cont…

“Not Getting It Right” (Stekenjokk)



The perils of interpolating ore continuity from surface drill data are graphically illustrated in this small-scale section of the Stekenjokk deposit. Two gentle ore horizons were assumed, but the ore actually occurs in a tightly folded complex.

8.3 Geotechnical and Hydrogeological Models

- Failure of models can result in anything from pillar failure to mine flooding to multiple fatalities
- Economic consequences range from financial impost to mine closure
- Geology model is a major component of geotechnical model – same issues
- Structural and hydrogeological model also based on drilling and interpretation and data sets are also limited
- Models developed need to be adequate for global decisions during evaluation
    - Underground block caving
    - Open pit developed as series of cutbacks
    - Open pit with final wall development from start
- Lower confidence level during evaluation results in higher probability of changes during operation?
    - Trade-off for project management?
- No equivalent of JORC confidence categories – working on it (*Read and Stacey, 2009*)
- *Learning* also continues well into life of an operation

Risk Assessment Cont…

Geotechnical and Hydrogeological Models Cont…

Hydrogeological - Not getting it right

8.4 Mining Method

- Incorrect mining method can result in
  - Significant disruption whilst method is changed
  - Loss of reserve/resource
- Economic consequences range from financial impost to mine closure
- Open Cut instead of underground?
  - Unlikely from a technical consideration
  - Possible from a resource consideration
- Underground
  - Stability charts – transitional zone
- Conversion from one method to another?
- At operational level method might be correct but parameters incorrect
  - Equipment size
  - Bench heights
  - Sub level intervals
  - Not just negative, design parameters may be too conservative

8.5 Revenue Assumptions

- Revenue assumptions, especially commodity prices, are primary evaluation risk

- Revenue assumptions have potentially positive as well as negative risk

- Incorrect revenue assumptions
  - Go straight to the bottom line
  - Can result in mine closure
  - May require adjustment to cut-off grades and head grades resulting in
    - changes to reserves
    - compromised mining sequence

8.6 Evaluation Risk Management

- **Evaluation sequence is one of risk minimisation and progressive risk assessment is now a standard requirement of the process**
- At a high level, the sequence of scoping, prefeasibility and feasibility is risk adverse. Expenditure and commitment advance with increasing confidence
- At a low level, mine planning departments usually have formal protocols
  - Checklists to manage activities
  - Approvals by different departments (ie, geotechnical, survey)
  - Formal risk assessment exercises
- At a project level (dependent on project manager and company philosophy)
  - Large companies
    - Formulate project standards
    - Conduct formalised review by “experts”
    - Implement peer review s
  - Smaller companies
    - Similar process but often less formalised and routine
    - Outside consultants especially for major areas of risk ie resources

End of Part 2

Thank you for your Attention

Acknowledgements

Acknowledgements

GLOBAL RESOURCE
SOLUTIONS

This presentation borrows substantially from a training document prepared by the author in 2004 for Global Resource Solutions, a company that provides global client project management consulting services. The author gratefully acknowledges Global Resource Solutions for permission to use this material.

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