60 YEARS

Excellence in Mining Engineering Education

1961 - 2021 A Diamond Celebration

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Faculty of Engineering, Built Environment and Information Technology

Fakulteit Ingenieurswese, Bou-omgewing en Inligtingtegnologie / Lefapha la Boetšenere, Tikologo ya Kago le Theknolotši ya Tshedimošo

Inaugural Address
Prof Francois Malan

Rock engineering research as a prerequisite for sustainability and growth in the mining sector

Make today matter

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TODAY'S MINING SUPPORTS THE ACHIEVEMENTS OF TOMORROW

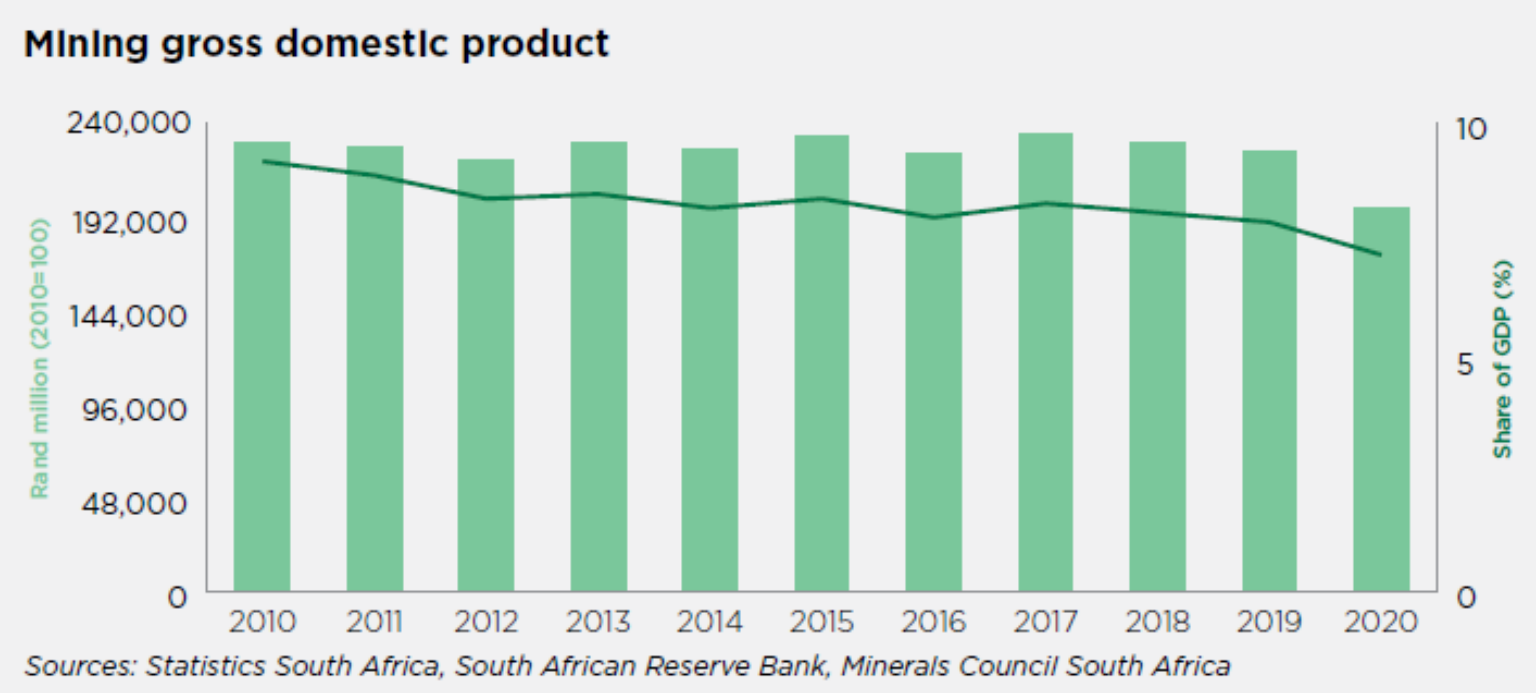
- Everything we depend on is either made from minerals or relies on minerals for its production
- Renewable energy, electric vehicles, and commercial space travel will all rely on an increased source of materials we need to mine!
- South Africa has a proud history of mining and especially with the early development of the field of rock mechanics

OVERVIEW OF THE SOUTH AFRICAN MINING INDUSTRY

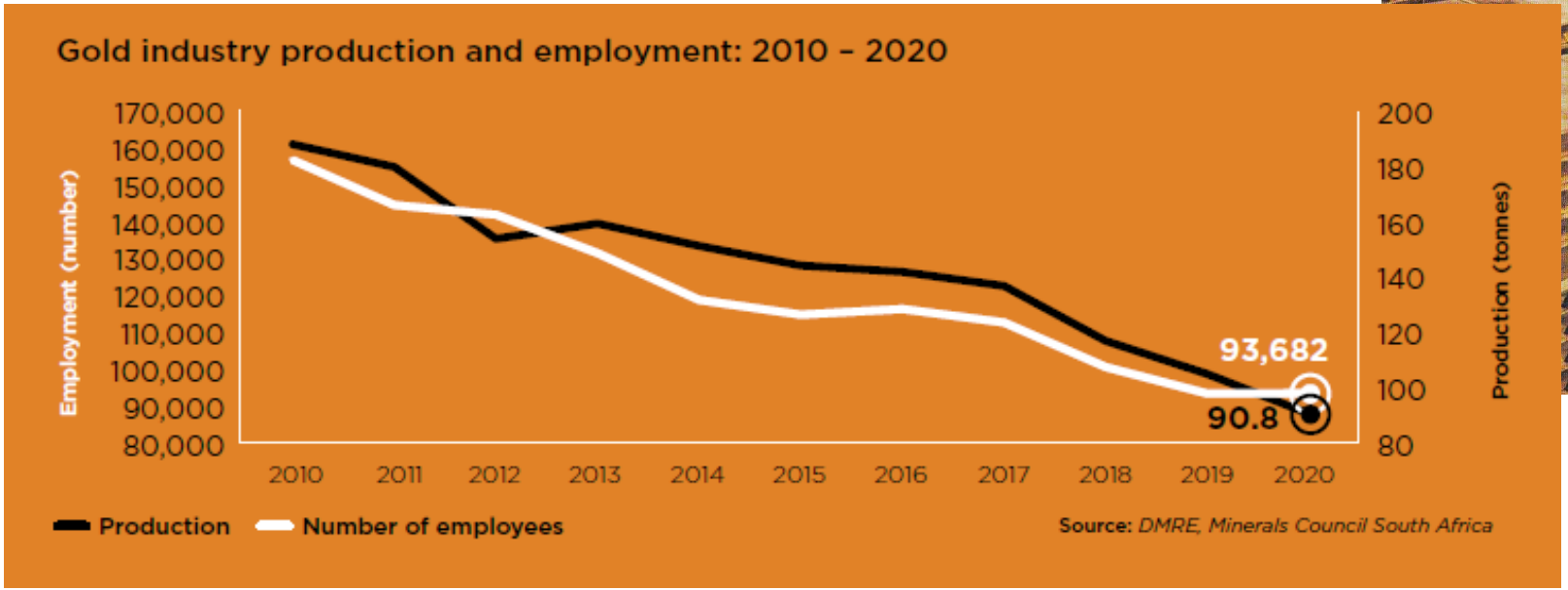
- 2020 – Mining contributed R361.6 billion to the country's GDP
  - employed 451 427 people

- South Africa has a huge mineral endowment
  - ranks first in terms of PGM, chrome and manganese reserves

Gradual decline of the South African mining industry

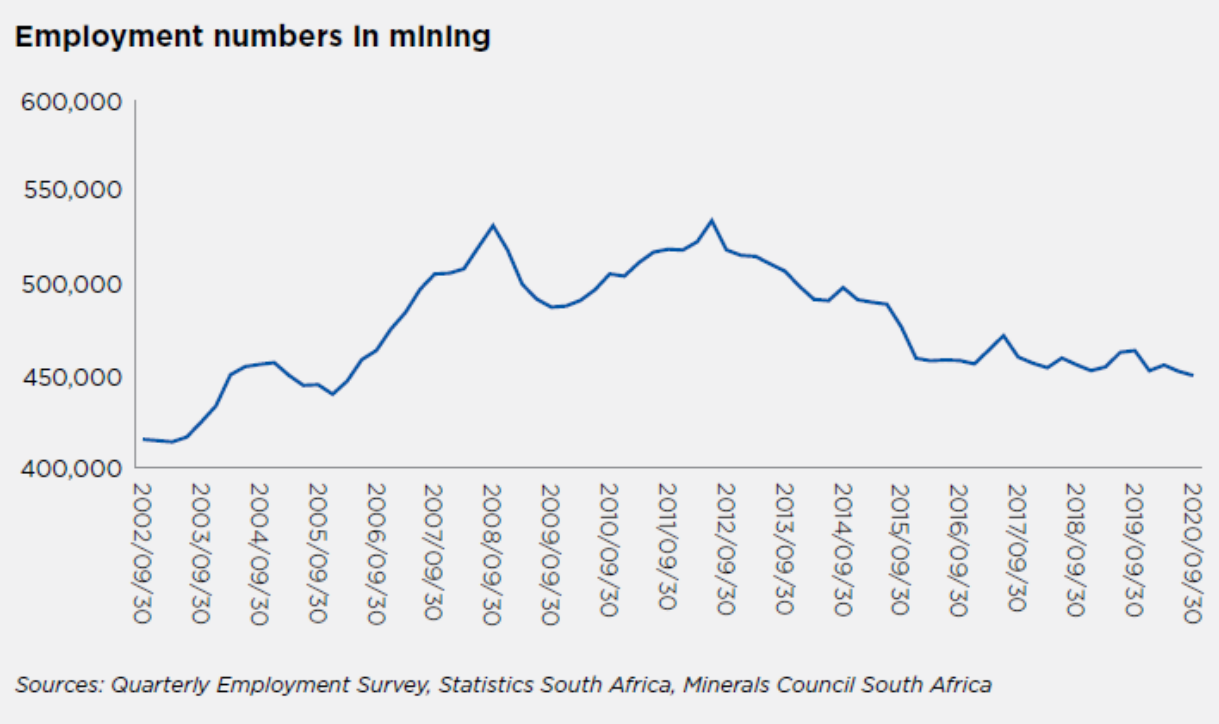


Gold production in South Africa



1000 tonnes in 1970!

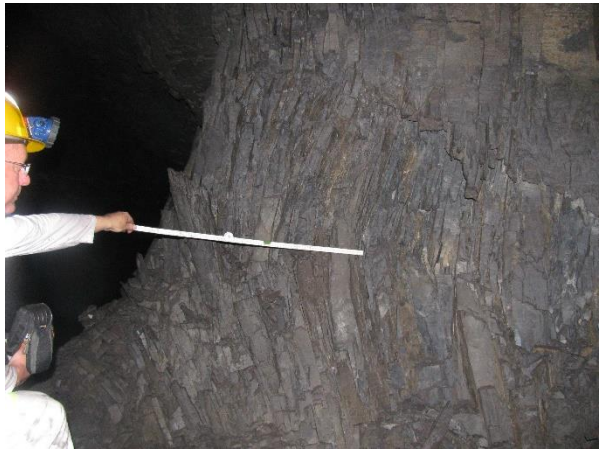
Employment in the South African mining industry



Rock engineering research to help turn this around!

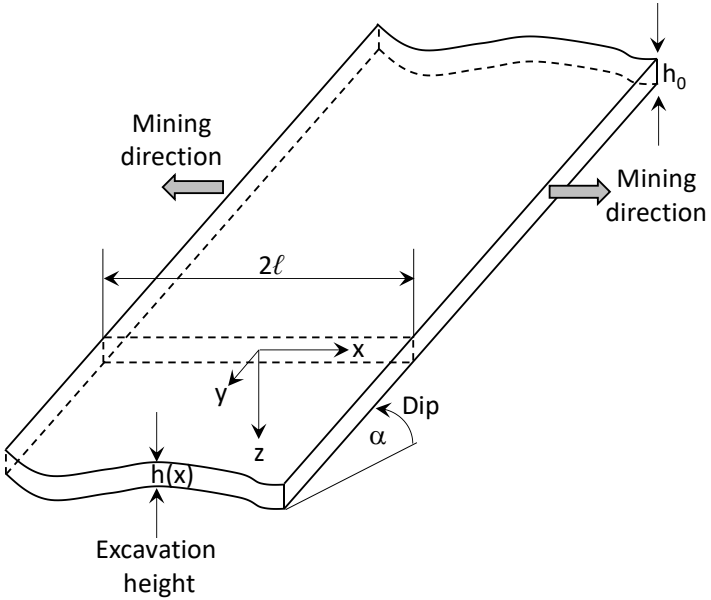
- Rock mechanics is a theoretical and applied science of the mechanical behaviour of rock
  - A branch of mechanics concerned with the response of rock and rock masses to the force fields of their physical environment

- We still do not understand many aspects!



Research required in South Africa

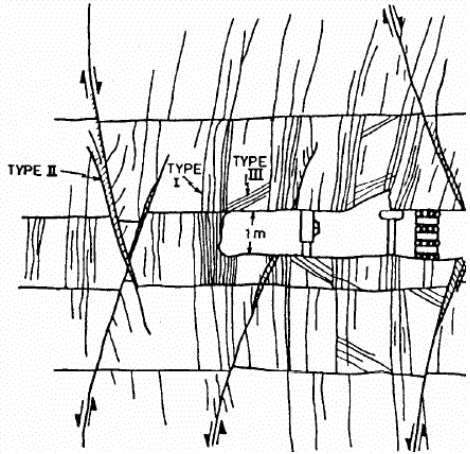
Many of our economic deposits are tabular orebodies (flat dipping, thin seams)



“Home-grown” rock engineering research required

- Still many unknowns in rock engineering associated with mining tabular deposits

- Leon Commission (1995): “*Furthermore, as no other region of economic significance has similar geometry, no mining industry outside South Africa pursues the solution to this problem.* ***The solution must therefore be found in South Africa****.”*



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Historic development of rock mechanics in South Africa

- Prior to the 1950s, mine layouts were based mainly on “trial and error” methods

- Two key factors resulted in a more directed research effort
  - The **rockburst events** (caused by seismicity) in the deep gold mines was recorded as early as 1908
  - The **Coalbrook colliery disaster** in January 1960

- In 1952 the Central Mining – Rand Mines Group commissioned a CSIR research team
  - Investigate if the stress around mining excavations can be determined by mathematical analysis

- In 1956 the Transvaal and Orange Free State Chamber of Mines agreed to assume sponsorship of the research programme
  - The research effort was accelerated in the 1960s by the Coalbrook disaster

The Coalbrook disaster

the wretched compensation paid to African miners.

The fact is that no pension is paid to the families of African miners killed at work and the lump sum handed over to widows and children is pitifully small and miserly.

THE FACTS

Here are the facts. The compensation paid is a lump sum of three years' wages calculated on the basis of the miner's pay rate and the number of his dependants, with £180 taken as the minimum pay level.

A widow without children draws

ANC volunteers march in formation at the Clydesdale Memorial Meeting.

Coalbrook: drill breaks down

28/1/60 Rdm

A new shaft to trapped men

STAFF REPORTER

BLACK AND WHITE MOURN DEAD MINERS

JOHANNESBURG.

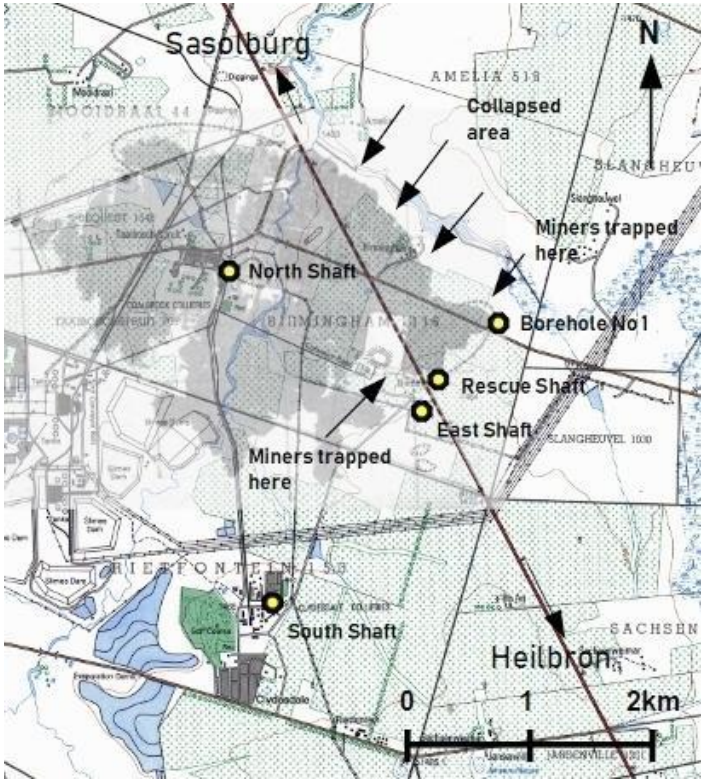
"WE SALUTE OUR COMRADES GONE, AFRICA'S HEROES, AFRICA'S PRIDE."

A choir from the Union of Southern African Artists sang "Oh Lord it is so sad to mourn, it is so sad to be in sorrow", a trumpeter played the strains of Inkos' Sikelele i'Afrika, and women in the audience

profits making companies are making."

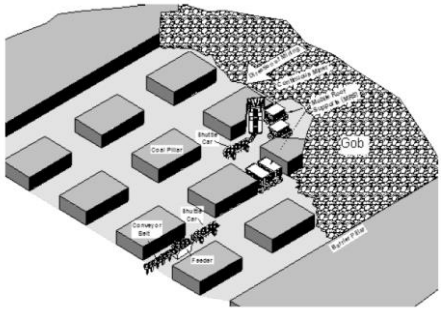
Mr. Moses Mabhida said: "These workers [illegible] never see South Afri

QUEEN SENDS

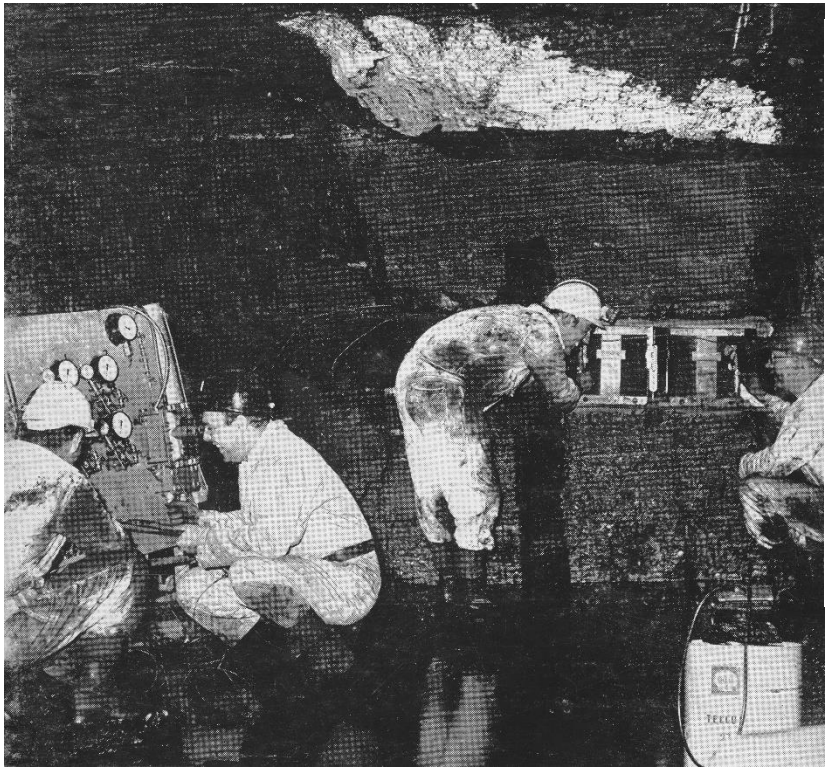


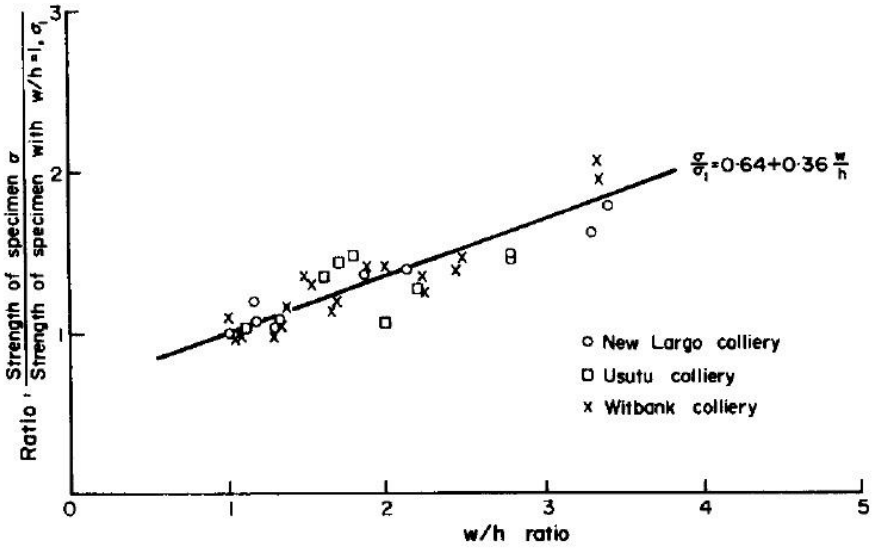
The aftermath of the Coalbrook disaster

- Pillars over an area of 324 hectares collapsed
- Rock mechanics research to find a method to determine coal pillar strength was given priority
- Salamon and Munro (1967) published their famous *empirical* coal pillar strength formula
  - $\sigma_p = 7.176 \frac{w^{0.46}}{h^{0.66}}\ MPa$
- Widely accepted in coal mining industry up to the present day
- One of the breakthroughs in rock mechanics that is keeping the lights on!



Numerous underground experiments to verify coal pillar strength

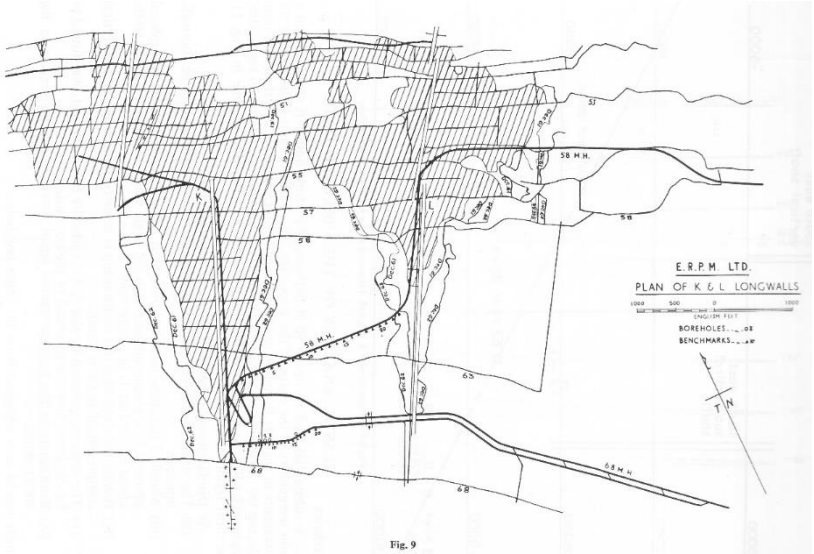




Should we rather use a “linear formula”?
Bieniawski and van Heerden (1975)

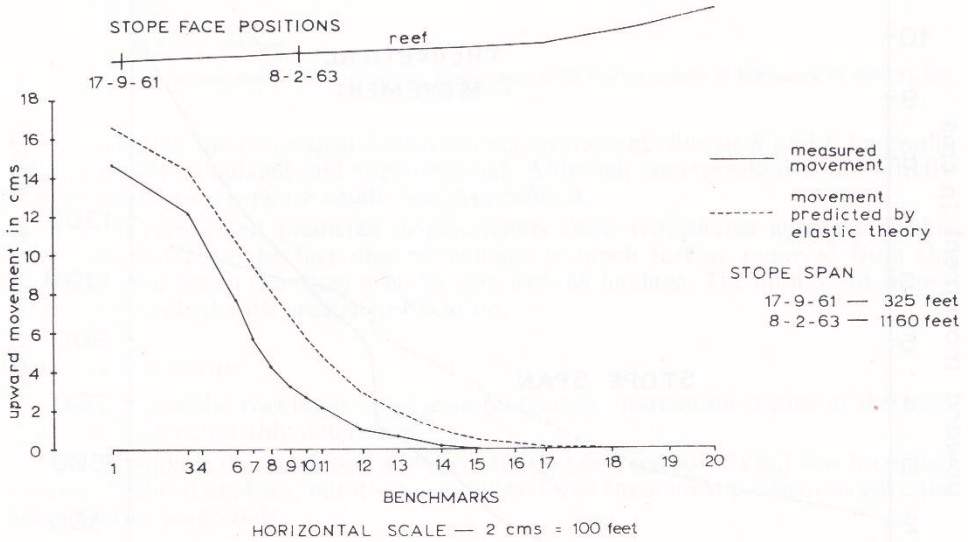
Major breakthrough in gold mine layout design 1960's

Elastic theory adopted

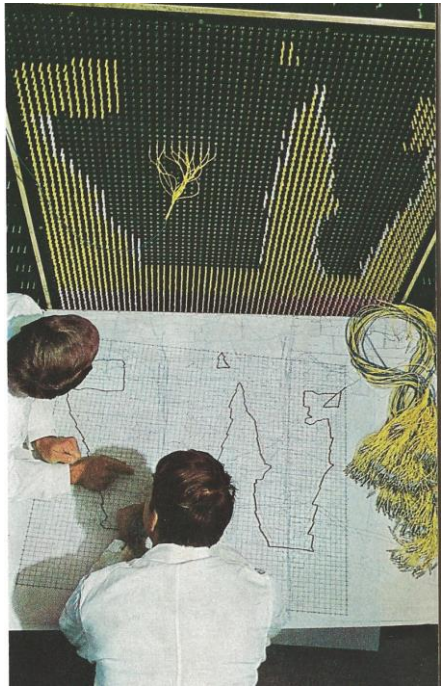


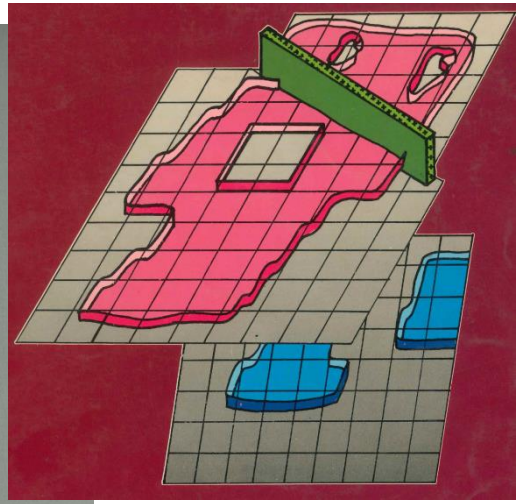
Displacements in hangingwall tunnel measured for a period of a year while longwalls below it advanced

Measured movement agree well with elastic theory



Elastic theory made stress simulation possible



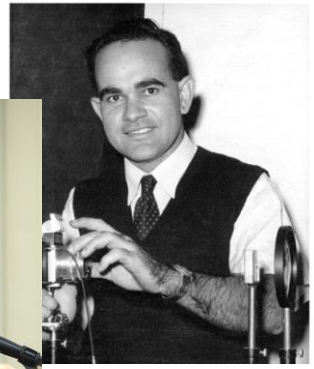


Coded by Prof John Napier

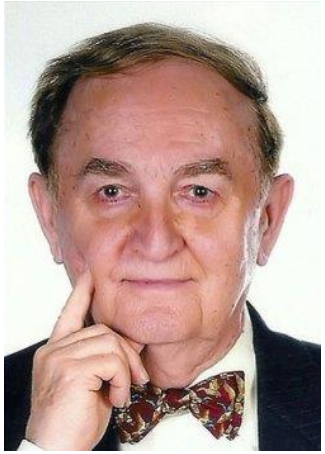
Electrical analogue and early MINSIM simulations in 1970s and 1980s

And the popular design concepts of **APS** and **ERR** were born!

World famous South African personalities in Rock Mechanics

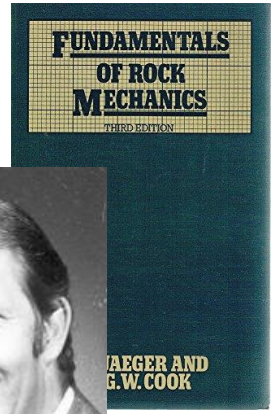


Evert Hoek
(Hoek and Brown criterion)



Z.T. Bieniawski
(Rock Mass Rating)

MDG Salamon
(Analytical solutions Face element principle)

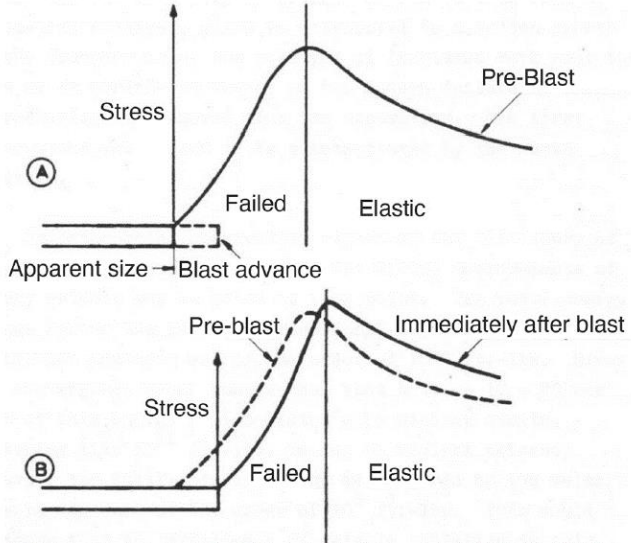


NGW Cook
(Elastic theory)

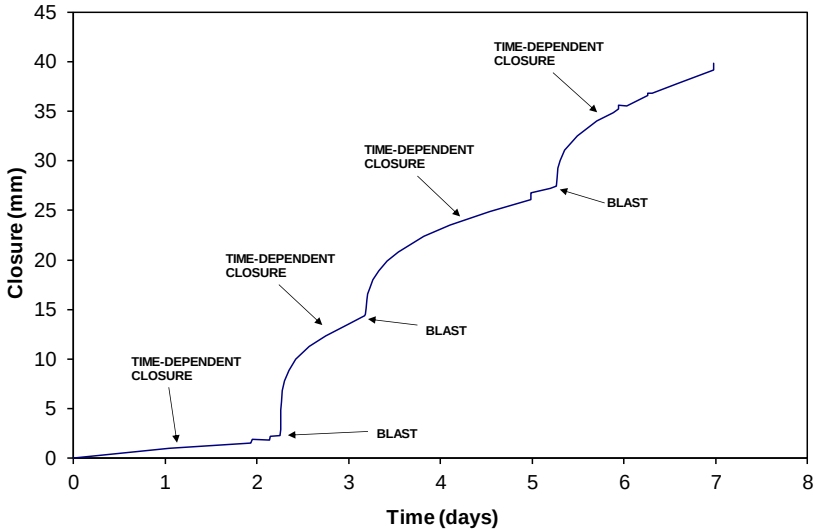
Wonderful foundation laid. Need to build on this.

Drawback of elastic theory

- Cannot simulate the fracture zone
- Cannot simulate the time-dependent response of the rock mass and mining rate



Recognized by Hodgson (1967)



Time-dependent closure measurements by Malan in the 1990s

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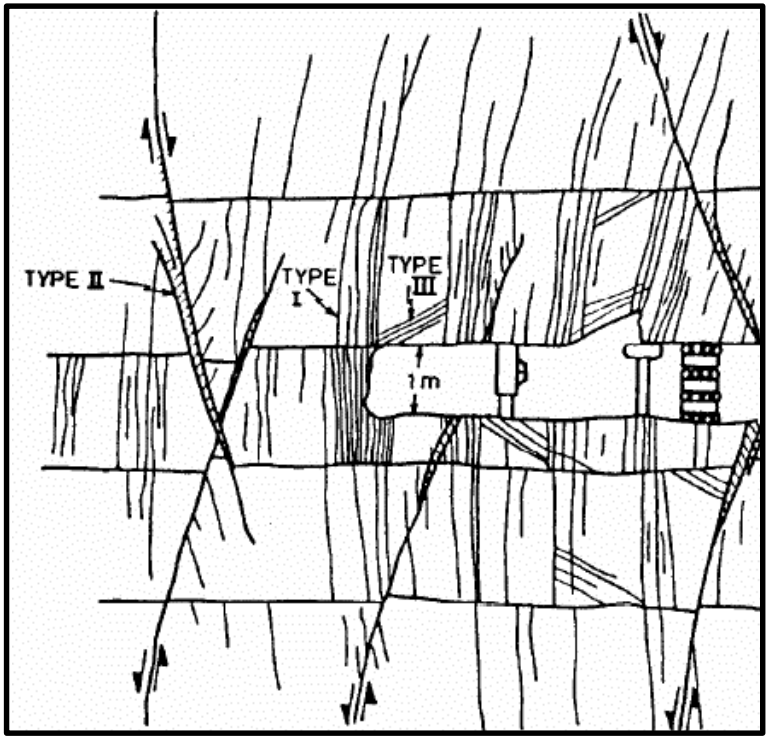
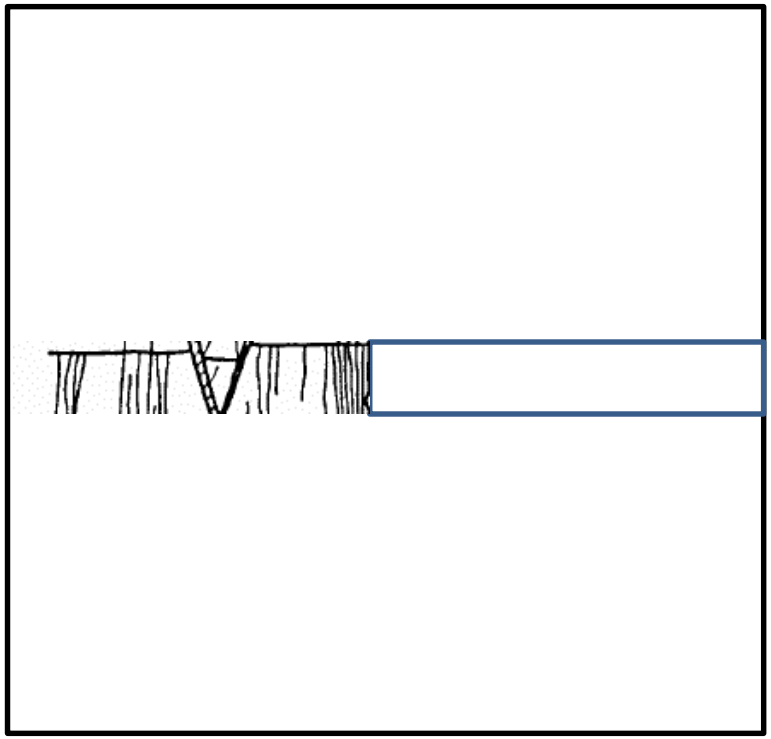
Recent developments: Allow for face crushing in models



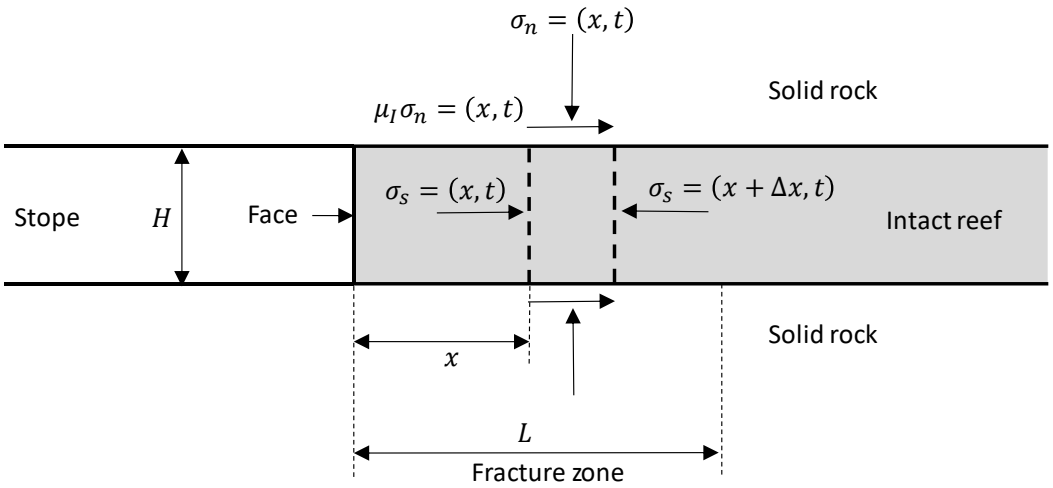
Reality underground



Improvement over elastic models

Details of the limit equilibrium model

- Assume a time-dependent limit equilibrium relationship between reef normal stress σ_n and reef parallel stress component σ_s

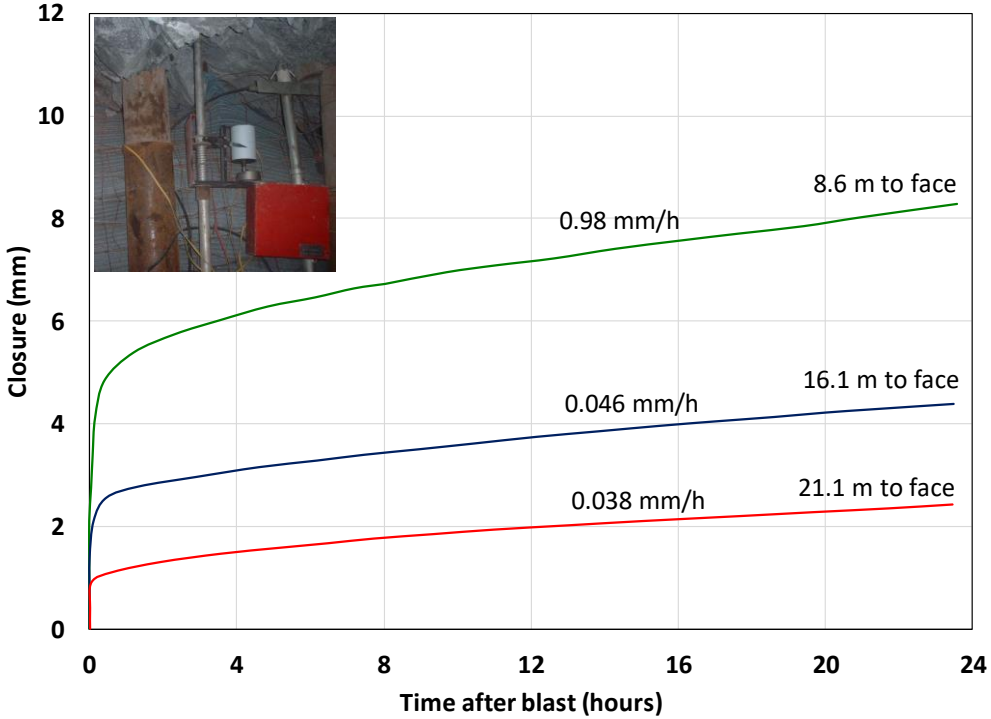


Parameter	Value
Intact strength intercept, σ_c^i	60 MPa
Intact strength slope, m_i	7
Initial residual strength intercept, σ_c^0	4 MPa
Initial residual strength slope, m_0	7
Final residual strength intercept, σ_c^f	2.5 MPa
Final residual strength slope, m_f	2
Effective seam height, H	5.5 m
Intact rock Young's modulus, E	70 GPa
Intact rock Poisson's ratio, v	0.2
Intact seam stiffness modulus, k_s	16500 MPa/m
Fracture zone interface friction angle	30°

(Napier and Malan, 2018)

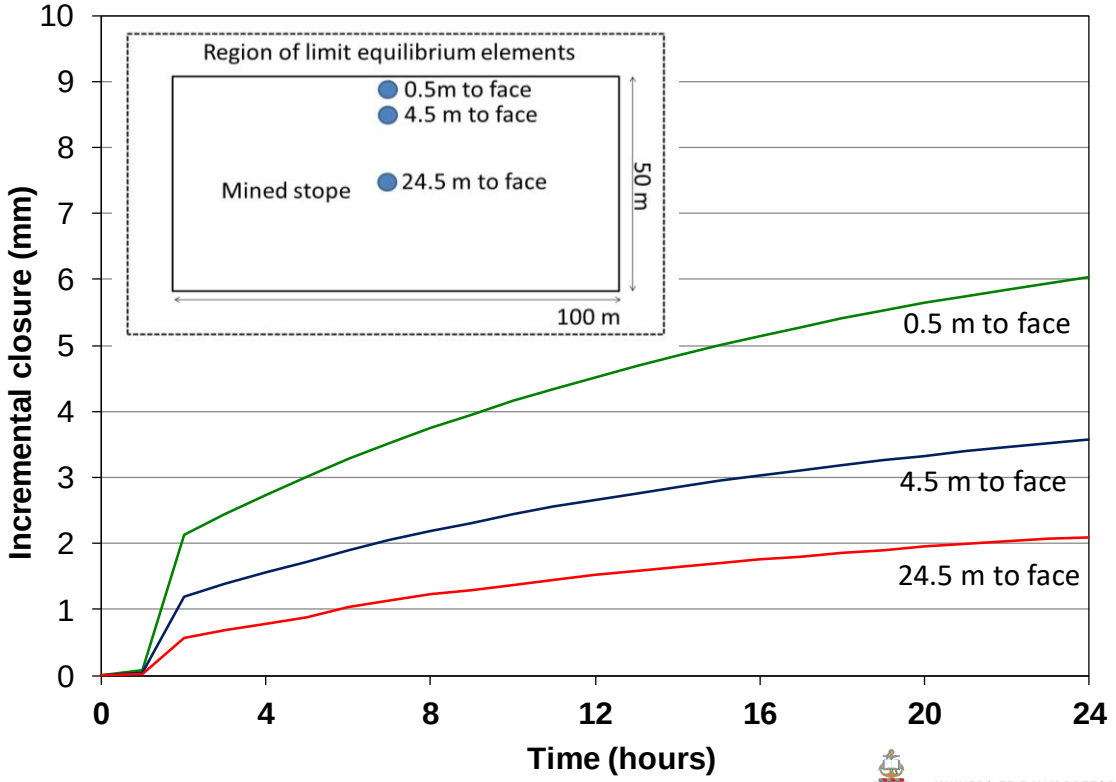
Closure data recorded from an actual stope

- Cannot simulate this time-dependency with elastic theory
- Earlier attempts to simulate with viscoelastic theory only partially successful
- Caused by the time-dependent growth and mobilization of the fracture zone

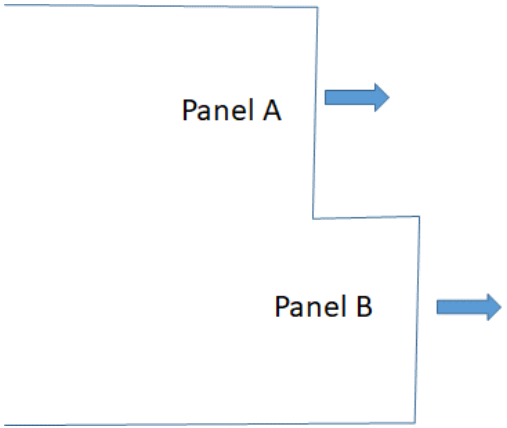


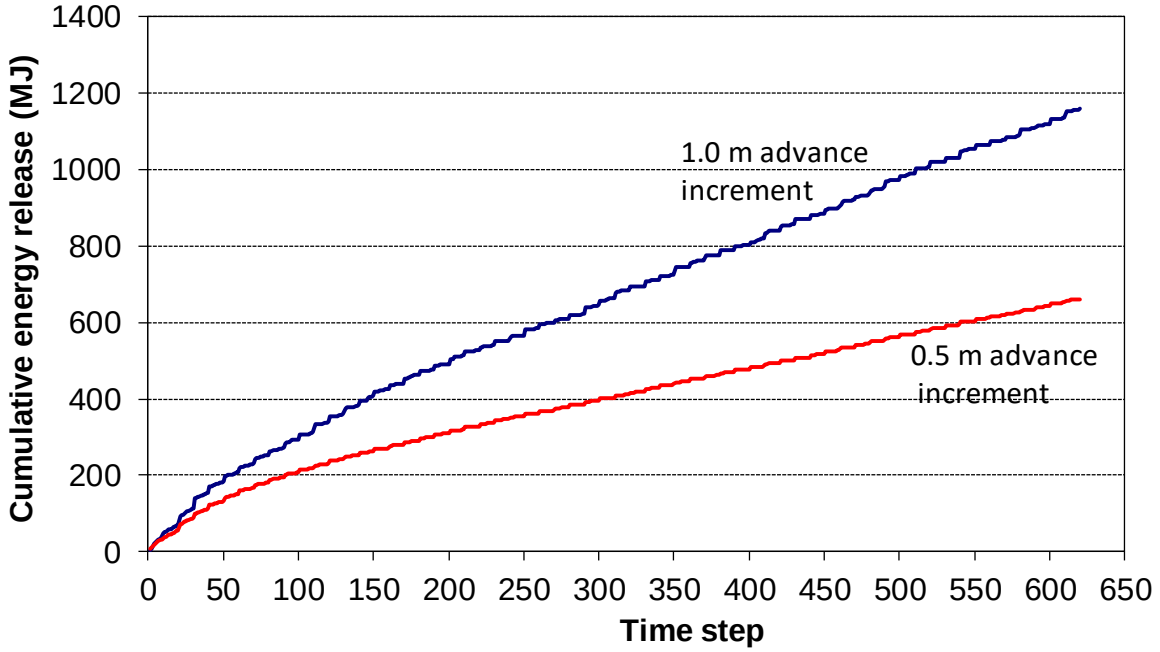
Simulation of closure data with the limit equilibrium model

- Much better approximation of actual underground closure
- It is problematic to calibrate the large number of parameters in the model
- This highlights the need for ongoing closure monitoring in underground stopes



Can now simulate mining increment size and mining rate



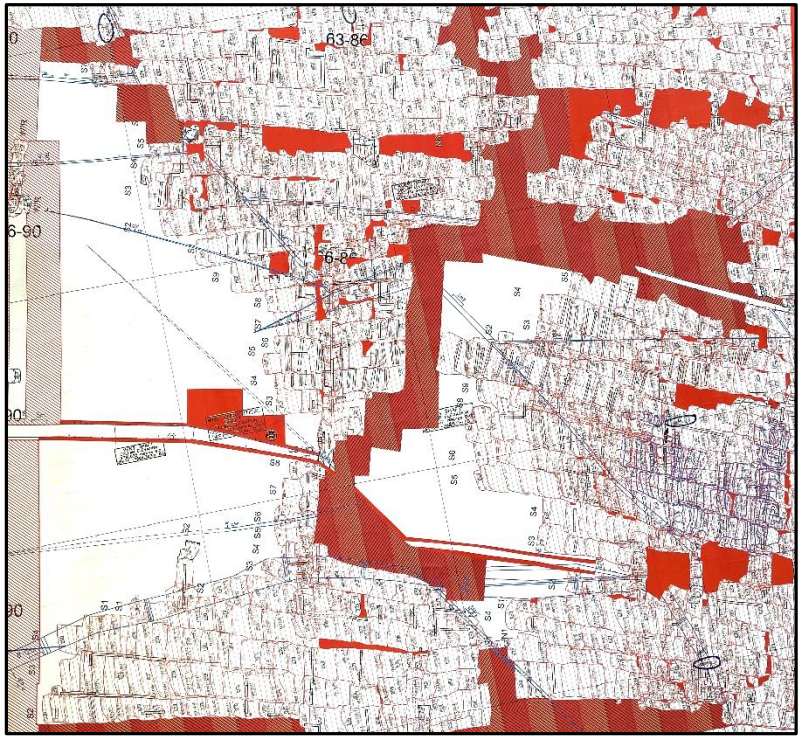


Two different advance options:

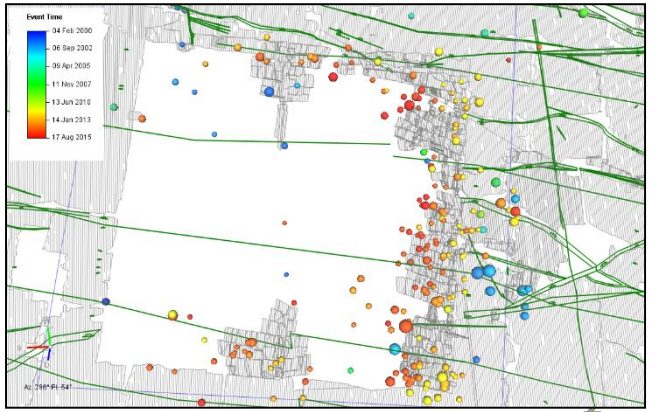
- Blast 1 m increments on A and B on alternative days
- Blast 0.5 m increments on A and B every day

Currently testing this approach on actual layouts

A current area of research



- Closure measurements and seismic data to calibrate model
- Need to verify that a failure model restricted to the plane of the reef is useful approximation



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1. Introduction and need for rock engineering research
2. Historic development of rock mechanics in South Africa
3. Simulating the effect of the fracture zone
4. **Design of rockburst support**
5. Current research on hard rock pillar strength

Design of rockburst support

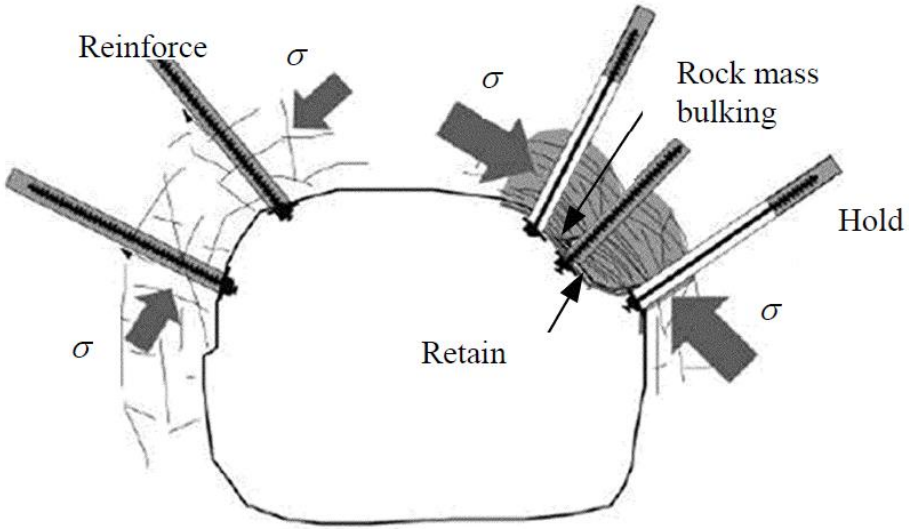
Rockbursts caused by seismicity still a problem in deep gold mines

Damage to an access tunnel

Damage in a stope face

Key functions of rockburst support

- **Reinforce** (strengthen and control bulking)
- **Retain** (prevent fractured blocks falling between reinforcing elements)
- **Hold** (anchor reinforcing elements in stable ground).



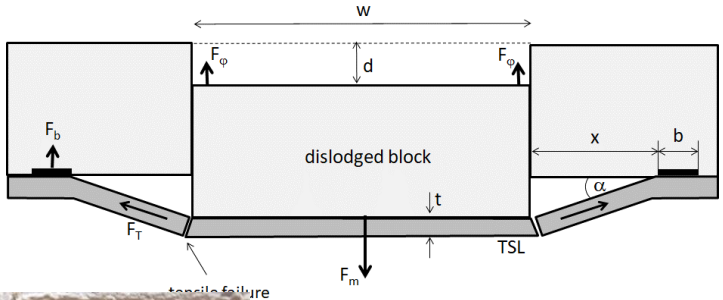
Area support in haulages versus stopes

New generation mesh

A current area of research

Thin spray-on liners

A current area of research



Du Plessis and Malan (2021)

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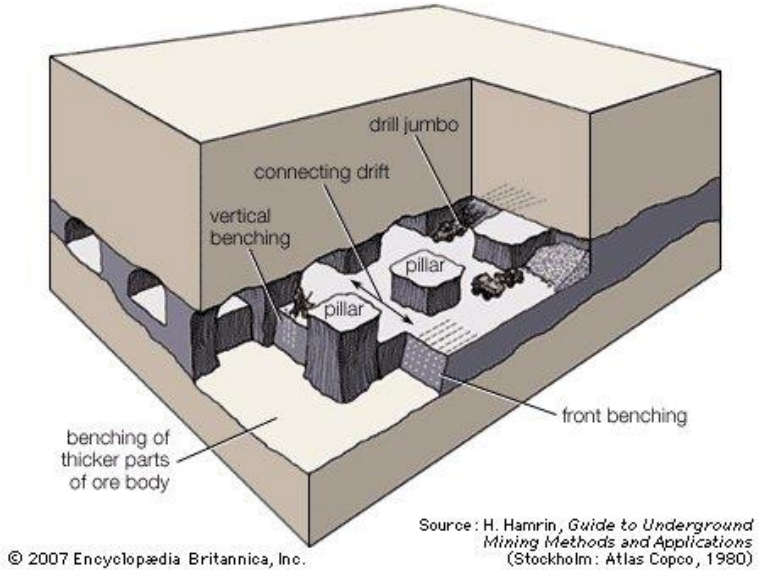
Current research on hard rock pillar strength

Bord and pillar layouts used in shallow manganese, chrome and platinum mines



Effect of depth on extraction ratio

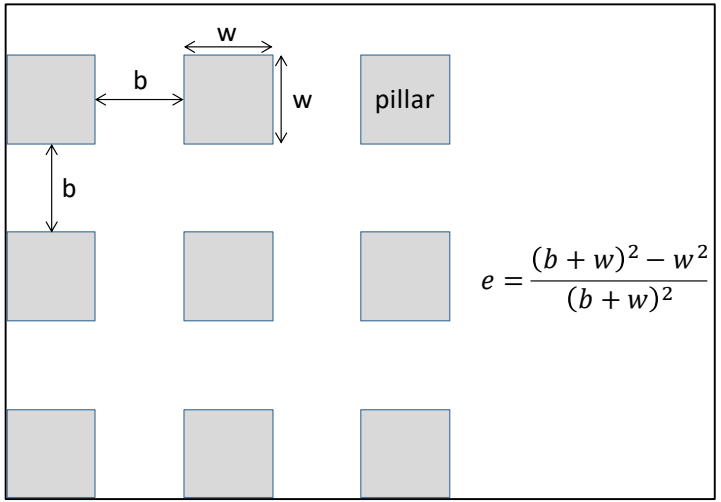
Most operations use the empirical Hedley and Grant pillar strength formula from Canada

- Hedley and Grant power-law formula for pillar strength

$$\sigma_s = K \frac{w^{0.5}}{h^{0.75}}$$

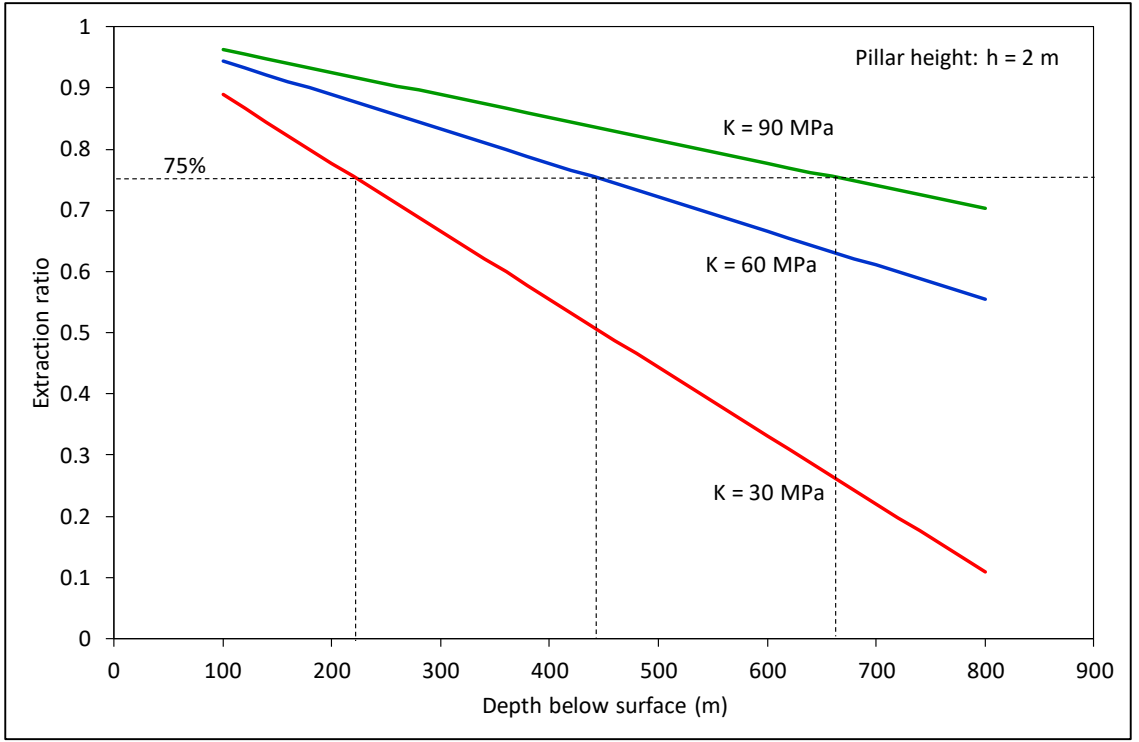
- Design for a Factor of Safety F_s

- The extraction ratio e is a simple decreasing linear function of the depth H



Effect of depth on extraction ratio

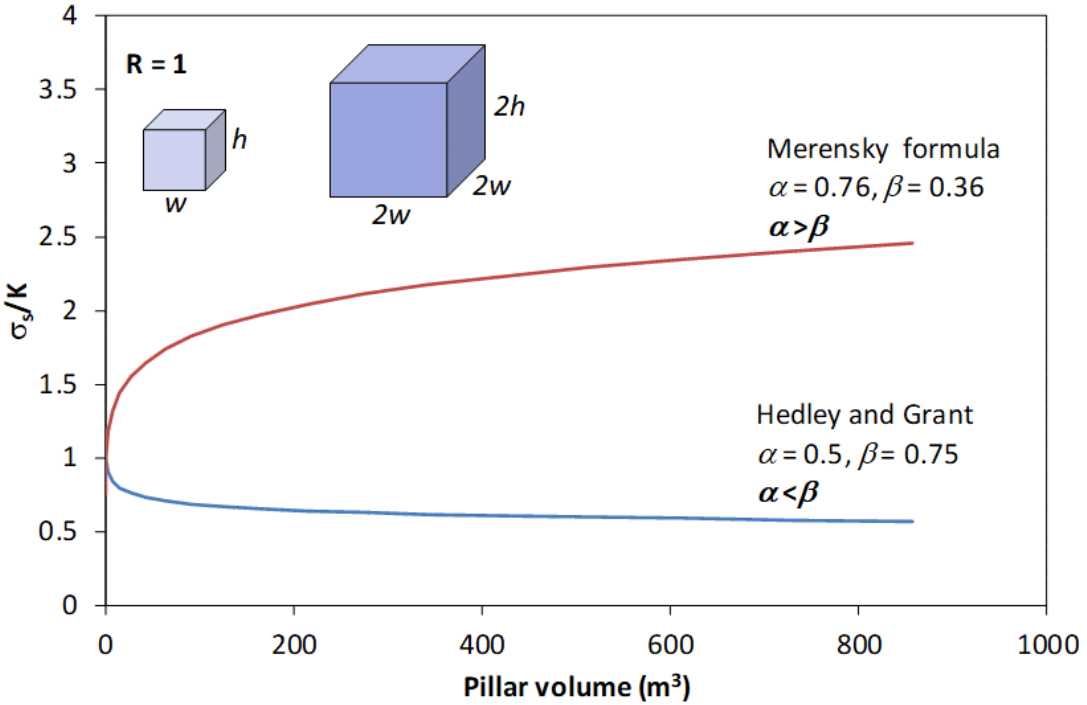
- Low pillar strength will make the mines uneconomical at depth
- Critical to understand pillar strength much better and this is the current focus of my research



Home-grown pillar strength formula required

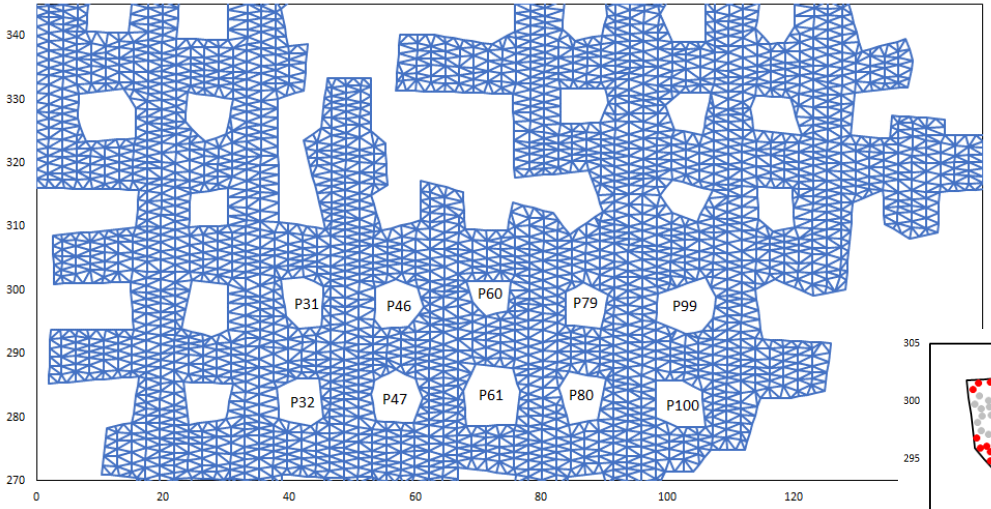
Uncertainties about power-law formula

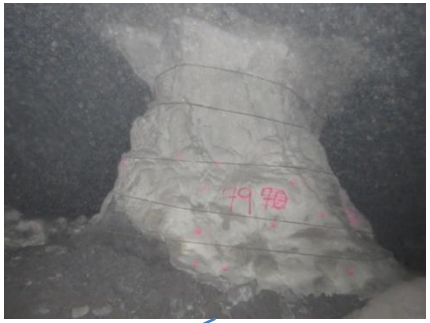
$$\sigma_s = K \frac{w^{\alpha}}{h^{\beta}}$$

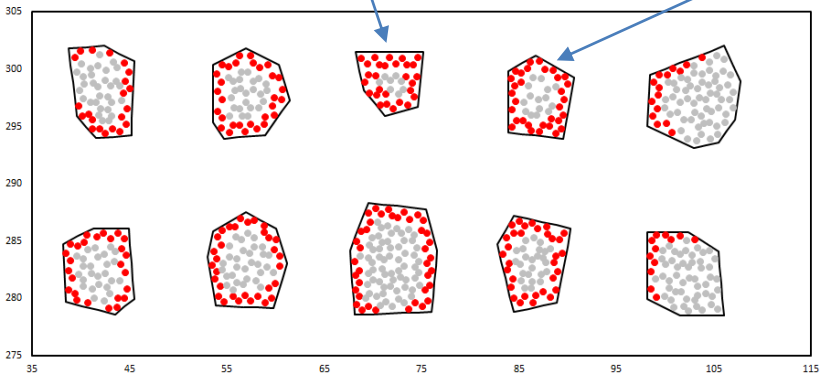


Simulating pillar failure and time-dependent scaling

A current area of research



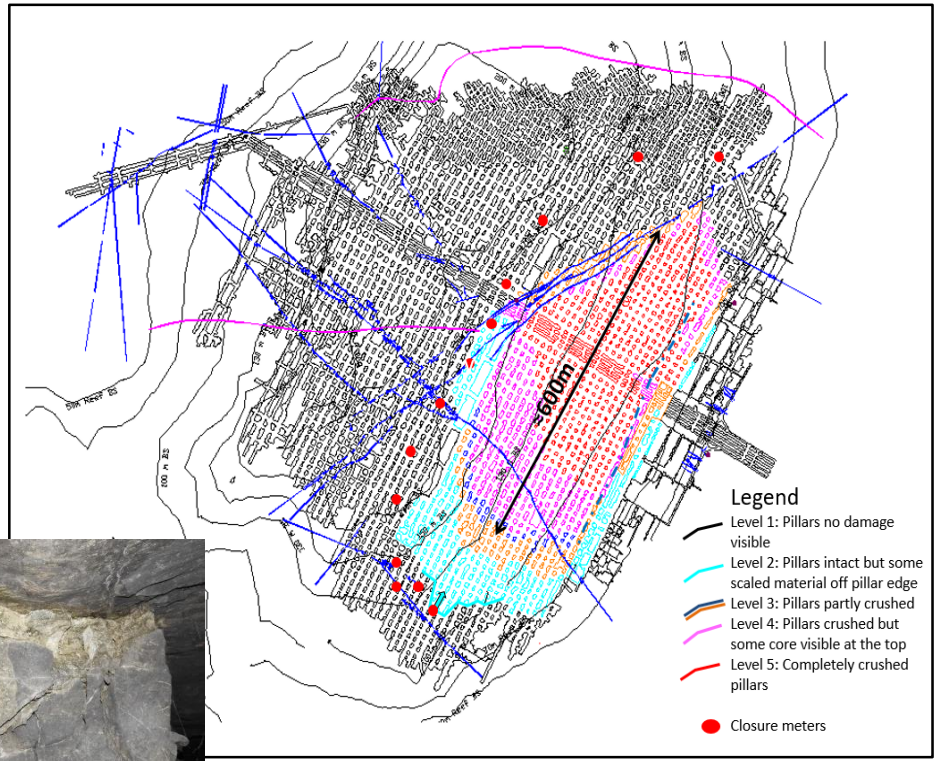




Assume a limit equilibrium relationship between reef normal stress σ_n and reef parallel stress component σ_s

Pillar failure caused by weak layers

A current area of research



Acknowledgements

- The Harmony Gold Chair of Rock Engineering and Numerical
- Northam Platinum
- Assmang
- Impala Platinum
- Gold Fields
- SAMERDI

Acknowledgements

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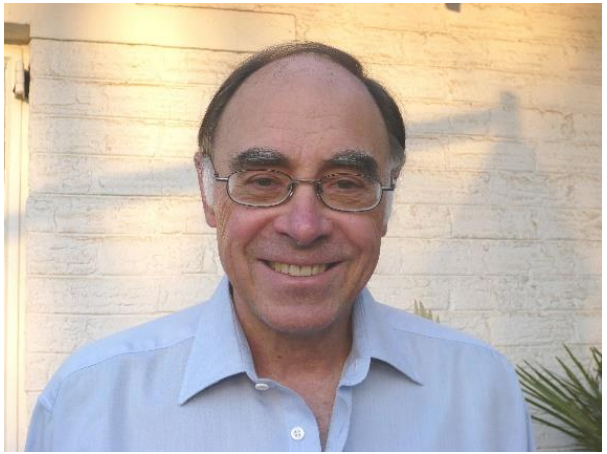

Prof John Napier

Acknowledgements

Thank You