Question 1

Multiple Choice

1.1.	D		(2)
1.2.	B		(2)
1.3.	A	(D also accepted)	(1)

A lot of you said Griffith. Professor TR Stacey published the "extension strain criterion" which was (to some extent) based on the Griffith-published understanding of rock failure and crack analysis. - I was however lenient here.

1.4.	D		(1)
1.5.	C	(Sn = 15 MPa not 14 MPa!)	(2)

Note that a typo was found on Q 1.5 in the issued paper. ("14 MPa" should have read 15 MPa). Q1.5 was thus removed from the marking.

1.6.	A		(2)
1.7.	C		(2)
1.8.	C		(2)
1.9.	D	(note :- Nm and Joule are the same units)	(2)
1.10.	C		(2)
1.11.	B		(2)

Wrong answers were **NOT** negatively marked.

TOTAL : 20 - 2 = 18

Question 2

Note:-

- you were asked to discuss the new environment and explain **<u>what would be different</u>** from the old one. This implies that you need to discuss both the old and new environments in your answer. Discussing only PT will likely earn you only 50%.
- Also a lot of you described typical intermediate depth PT mines (many of which now lie well above 1000m in depth). My question specifies depth < 800m so don't expect marks for talk of seismic or stress related failures - failure is primarily geology and geometry driven at this depth range.

The below is a guideline - other sensible comments also accepted (as long as the main headings were addressed). Generally half a mark per valid point - below I have listed more than required.

2.1. General geological setting (4)

	Gold (Deep) K <1.0	Platinum (500-800m) K > 1
Formation **(1 mark - 1/2 Gold, 1/2 PT)**	**Sedimentary Basin.** Formation via deposition of weathered sediment. Witwatersrand Basin Possibly linked to Vredefort dome (asteroid impact site)	**Large Volcanic intrusion** Orebodies formed by intrusion of magma under pressure and then cooling. Rustenburg layered suite
Rock types **(2 marks)**	Quartzite Conglomerate Shales Lava (above VCR) **(Sedimentary / Metamorphic)** With localised dyke intrusions	Pyroxenite (dark minerals) Norite / Anorthrosite (lighter minerals, more brittle) Other ... **(Igneous)**
Native rock temperature and vent requirements **(1 mark)**	Hotter because it is significantly deeper. Constant ventilation required. Refrigeration (cooling) required at depth in excess of approx. 2000m	Will require ventilation flow, but cooling will likely not be necessary. Generally the host rock has a higher temperature at same depth (PT rocks have a higher thermal gradient), but because it is shallower the PT operation will be cooler than the Gold one **Bonus mark:** In PT the thermal gradient may be higher but the thermal conductivity is however lower (once it is cooled, it stays cool longer)

2.2. Main Rock Engineering focus (8)

	Gold (Deep) K <1.0	Platinum (500-800m) K > 1
Stress environment and its influence **Regional support roles**	High stresses (Virgin vertical stress of 67 - 81 MPa). Stress interactions are large and cause damage. Rock failure tends to **be stress driven.** **Positive:-** clamping stress (due to dilation of fractures) in hangingwall promotes stability. To reduce the span and thus **control volumetric closure, ERR** and ESS.	Lower stresses (Virgin vertical stress of 16 - 26 MPa). Stress interactions are small and do not control excavation placement. Rock failure tends to **be geologically driven.** No clamping stress To reduce the span and thus **reduce the extent of the tensile zone in the hangingwall.** In some cases (shallower) regional pillars designed to carry the **overburden weight to surface**
Failure mechanisms and related risk	**Failure is both stress <u>and</u> gravity driven** Stress related fracturing of the rockmass surrounding excavations (fracturing / scaling). Sudden and violent seismic release on the face OR on structures. Small localised FOG's Keywords like scaling, face bursting, seismicity etc	**Failure is geology and geometry controlled and is Gravity driven** Joint controlled failures Structure related failures
Rock Mass Quality	Plays a role that is far less prevalent than that played by the local stress environment. In Gold one rather utilises RCF which has a small rockmass quality measure in its "f" factor.	Plays the main role in determining excavation stability. In PT one can use Q, RMR, MRMR etc to assist ion classification and design
Influence of Geology	Can result in either 1. Strata control problems due to shallow dipping contacts OR 2. Risk of seismicity due to overstressing (ESS)	1. Strata control problems due to shallow dipping or low cohesion contacts 2. Promotes large scale failures

2.3. Instope design and layout fundamentals (8)

	Gold (Deep) K <1.0	Platinum (500-800m) K > 1
Suitable stope support and design	Regional stability pillars to reduce spans and thus overall closure. Instope support **(yielding)** Stiff **yielding** elongates, packs on gullies and backfill to control closure. Design is based on BOTH Energy absorption and Support Resistance.	Regional stability pillars with instope crush pillars designed to both reduce and support the tensile zone. Instope support **(STIFF and non-yielding)** Stiff mine poles, and cluster sticks to support large hangingwall fallout, packs and instope bolting. Design is focused on Support Resistance (unless seismicty is a known concern).
Gully layouts and geometry	**Rules exist and must be followed** Long ASG's to be avoided Lead Lags < 10m **Sidings to be left** on gullies Aimed at preventing stress driven damage from destabilising the gully	Rules are less important here as failure is not stress driven. A siding does however help with the stability of instope pillars (reducing the pillar W:H ratio)
Face shapes and mining sequencing	**Rules exist and must be followed.** Face shape to be controlled (Face-shape Index) Mine towards solid Optimise mining approach to structures (35° approach) Mine away from structure Etc	Rules are less important here from a stress point of view. Sequencing is planned around mining and vent constraints but face shapes and lead-lags are still controlled to ensure better support installation and mining practices.
Protection of off-reef excavations	Keep tunnels deep in the footwall or hangingwall far away from mining (>60-100m below abutments) Tunnels **must be de-stressed** Tunnels must be placed **away from geology** Damage predominantly expected on the sidewalls	Damage can (depending on conditions) be expected on the hangingwall. Can use haulage protection pillars to maintain vertical stress component (when arching is a problem). Generally smaller middlings between the reef and tunnels can be accommodated (30-40m) Destressing of tunnels may also be used but beware of increased hangingwall arching problems.

TOTAL : 20

Question 3

3.1. Theory

3.1.1. A = 0.50, b = 0.75 (hedley and grant with k = 1/3 UCS) (1)

3.1.2. 3 half-marks for naming parameters, 3 half-marks for discussion (3)

DRMS – Design Rockmass strength – a measure of rockmass strength based on both the UCS (insitu strength) and the MRMR (joint condition / blockiness). The higher the DRMS the stronger the pillar.

W – effective pillar width, wider is stronger.

H – Pillar height, higher is less stable (weaker).

3.2. Calculation (10)

Pillar strength: $\boxed{\textbf{Strength = DRMS * We^0.5 / H^0.7}}$

Rating (UCS) = 8 (From the table) **(1/2)**

DRMS = RMS = UCS x (MRMR – RUCS)/100 = 100 * (45 – 8)/100 = 37 MPa **(1)**

DRMS = RMS x adjustment factor (assumed to be 1.0 as MRMR already includes necessary mining adjustments)

We = 4*area/perimeter = 4*(5*8)/(2*(5+8)) = 6.15 m **(1)**

H = 1.5m

Pillar strength = 37 * 6.15^0.5 / 1.5^0.7 = 69.1 MPa **(1)**

Pillar stress:

25° dip is too steep to be assumed to be vertical. We have to use the full formula in this case.

Virgin vertical stress Sv = pgh = 3100 kg/m3 * 9.81m/s2 * 250m = 7.6 MPa **(1)**

k=1.5, thus horizontal stress Sh= 1.2 * 7.6 = 9.12 MPa **(1)**

Pillar area = 8m * 5m = 40m2

Total area = (10 + 8)*(10 + 5) = 270 m2

Extraction ratio (e) = (270 - 40)/270 = 85% **(1)**

Average Pillars stress APS = [Sv*Cos^2(25°) + Sh*Sin^2(25°)]/(1-0.85) = 52.4 MPa **(2)**

(NB. Only 1 mark given for APS calc if the flat reef formula APS = Sv/(1-e) is used. Student also looses other mark for calc of horizontal stress component sh)

Factor of Safety

FOS = Strength / stress = 69.1 / 52.4 = 1.32 **(1/2)**

FOS > 1.0 but is less than the suggested 1.5 or 1.6. Pillar will most likely <u>not</u> fail <u>but</u> should be redesigned to have FOS >1.6. **(1)**

NB! Only partial marks are given if units are not presented (i.e. MPa). Method marks allowed provided that the student is not reporting unrealistic numbers (i.e. virgin stress of 100MPa etc)

3.3. Calculation 2 (3)

Pillar strength stays the same = **69.1 MPa**

Pillar stress:

New vertical stress = 1.3 * Sv = 7.6 * 1.3 = 9.9 MPa **(1/2)**

New horizontal stress = Sh = 1.2 * 9.9 = 11.9 MPa **(1/2)**

Extraction ratio (e) = the same = 85%

Average Pillars stress APS = [Sv*Cos^2(25°) + Sh*Sin^2(25°)]/(1-0.85) = 69.1 MPa **(1/2)**

(No marks given for APS calc if the flat reef formula APS = Sv/(1-e) = 66 MPa is used)

FOS = Strength / stress = 69.1 / 69.1 = 1.00 **(1/2)**

FOS ~= 1.0. The pillars stability is on the border line. To be redesigned to have FOS >1.6. **(1)**

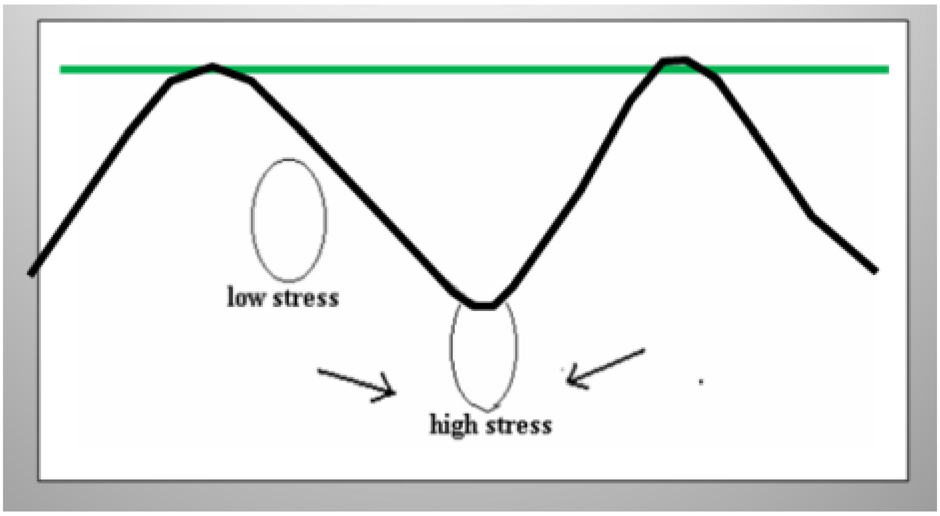
NB! Only partial marks are given if units are not presented (i.e. MPa)

3.4. TAT mountain question (3)

Mountains create non-uniform stress distributions (see below) (1)

TAT assumes the SAME depth throughout (i.e. a flat topography) (1)

When mountains are involved the virgin stress field should rather be assessed considering the geometry of the mountainous topography (i.e. **using numerical modelling** to determine APS) (1)



The influence of mountainous topography on virgin stress

TOTAL : 20

Question 4

4.1. Seismic system layout (5)

Below is a typical layout in sketches. To get full marks must have the basic flow of components 1 - 5 correct and should provide brief explanations of the functions.

1 = Geophones / Accelerometers (Measures displacement / acceleration)

2 = Remote acquisition unit or "MS" / "QS" box (Latest are called a "GS" box) (Collects output from various geophones and converts analogue signal to digital)

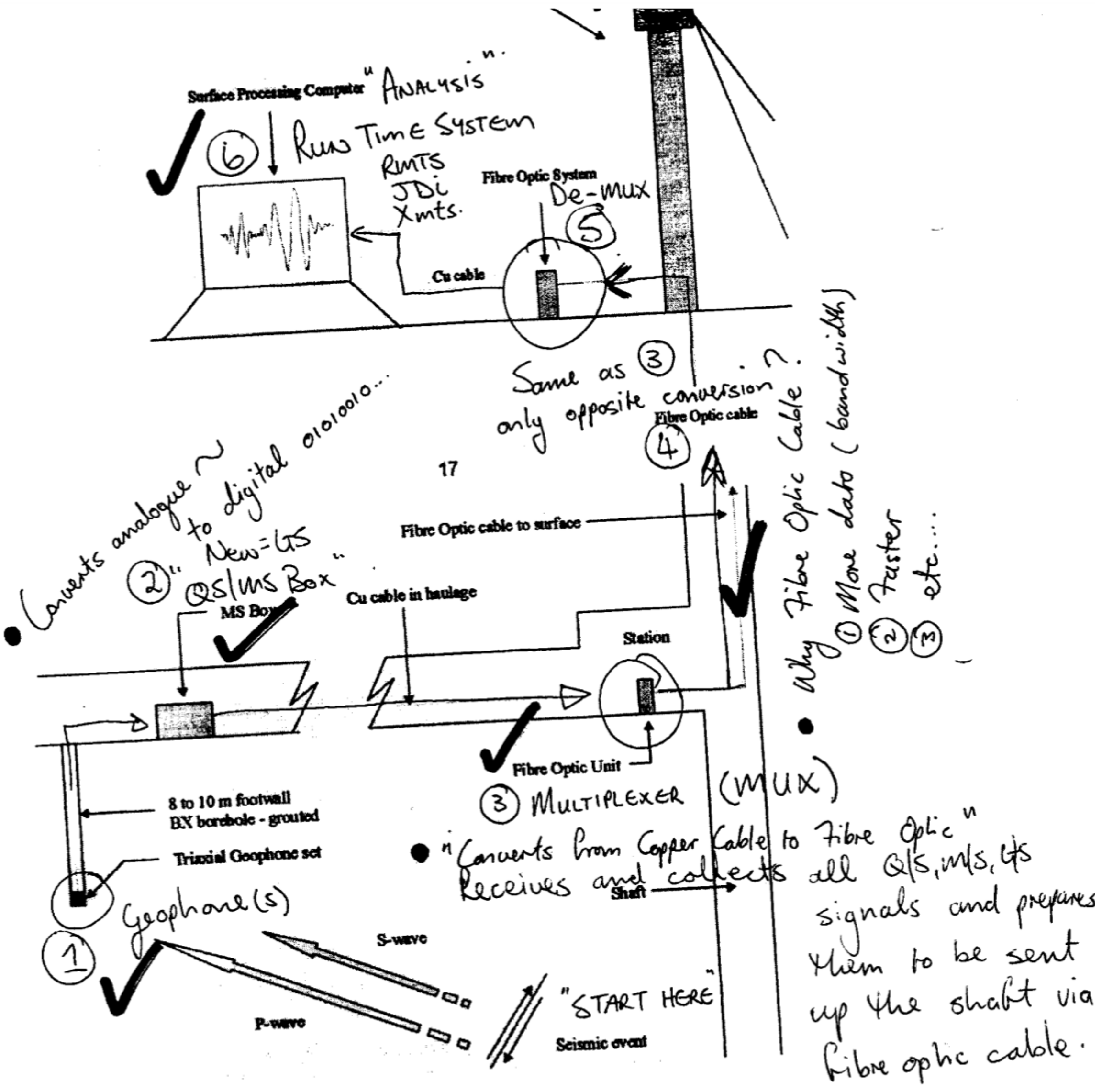
3 = Multiplexer (MUX). (Collects all signals and prepares then for transfer through a dedicated line up the shaft - this often includes conversion to fibre optic cable)

4 = Fibre cable (larger bandwidth, faster, more durable etc.)

5 = De-multiplexer - Does the opposite of the MUX

6 = RTS (Analysis and interpretations)

Other sensible configurations also accepted.



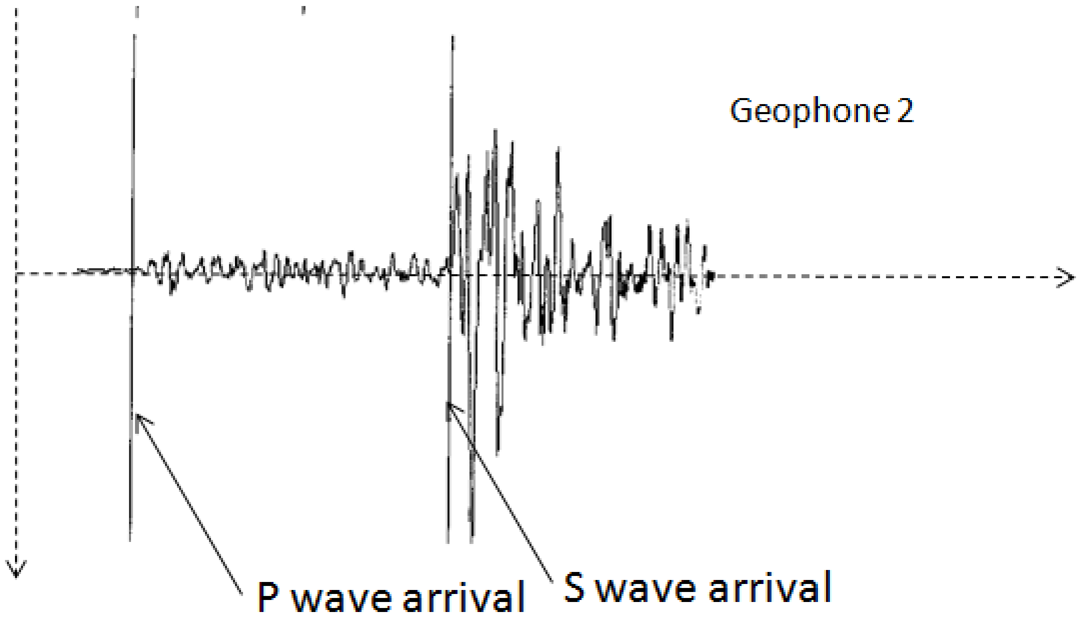
4.2.1. (1)

X axis plotting **Time** (usually milliseconds).

Y axis plotting **measured Acceleration** in m/s^2. (Other measured derivatives (displacement or velocity) also accepted)

(Some of you swopped the x and the y axes ??? Are we not taught at school that "x" is horizontal?)

4.2.2. (1)



4.2.3. (2)

<u>P wave - Primary wave (any 2 points)</u> (1)

- Compression wave. (has compressions and dilations)
- Direction of wave propagation = (is parallel to) direction of particle motion

(Note: you cannot say "direction is parallel to propagation"... direction of what?!)

- Faster speed of wave propagation (5400-5900 m/s)
- Can move through both solids and liquids

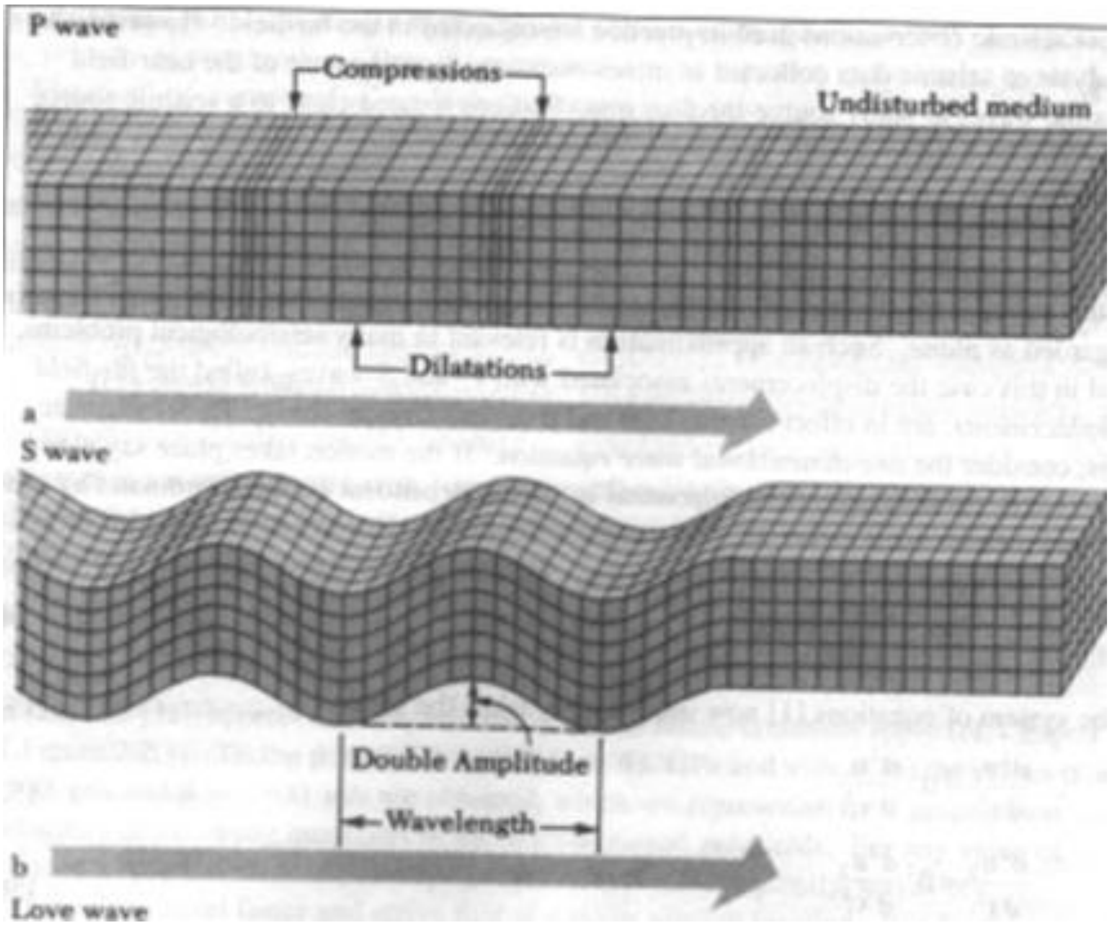
<u>S wave - Secondary wave (any 2 points)</u> (1)

- Transverse or Shear wave (has crests and troughs)
- Direction of wave propagation perpendicular to direction of particle motion

(Note: you cannot say "direction is perp. to propagation"... direction of what?!)

- Slower speed of wave propagation (3400-3800 m/s)
- Can only move through solids (liquids cant accommodate shear)

As per figure and discussions from the text book Chapter 5, pg 196



4.2.4. (1)

In geophone 1 the time difference between the P and S wave arrivals is smaller. Assuming that the P arrival times do not necessarily match in physical time, then Geophone 1's installation is closer to the event that geophone 2's.

Students could also mention that there is more noise coming from the geophone 2 signal.

4.3. GR graph (8)

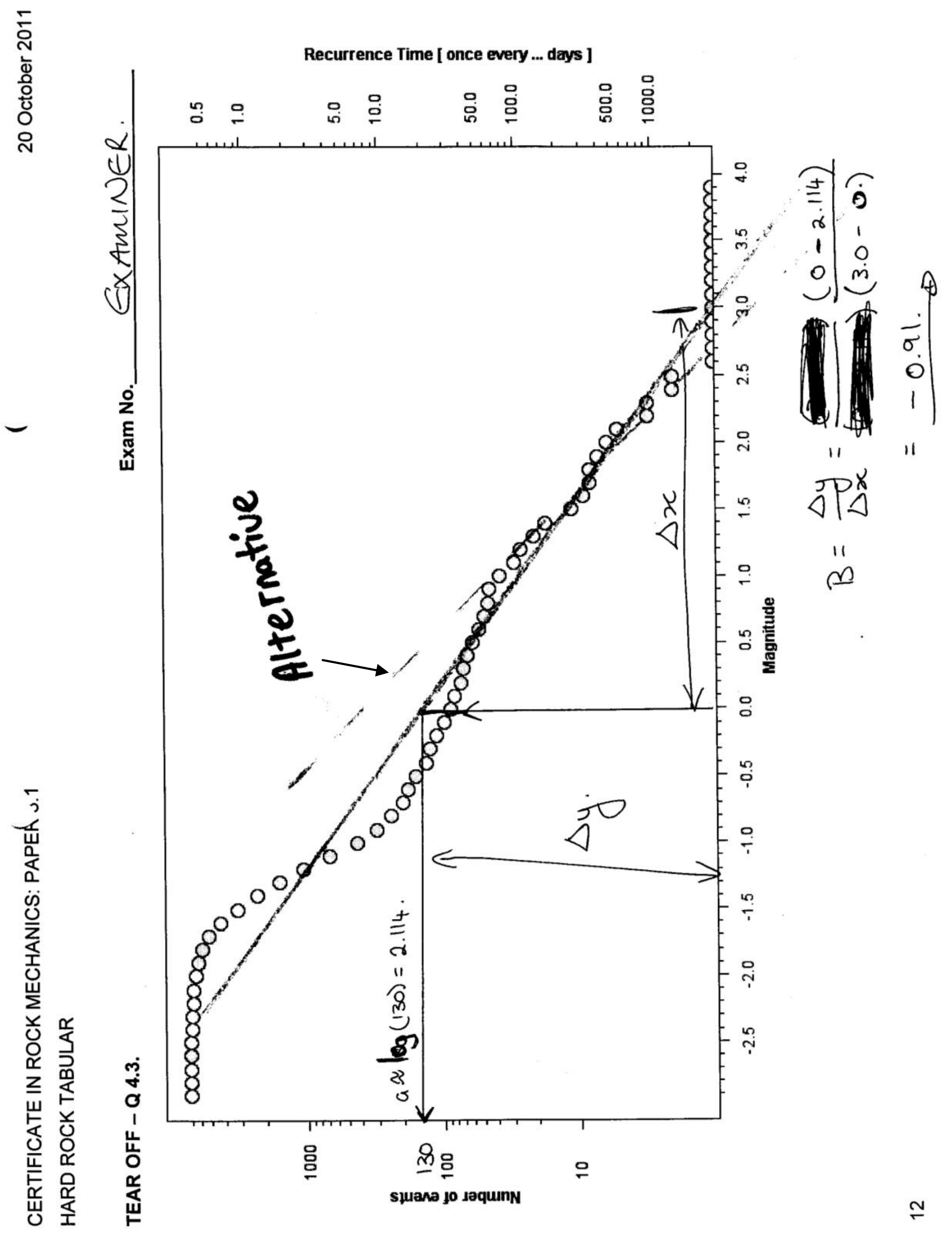
4.3.1.) GR = Gutenberg-Richter relationship (2)

The GR relationship defines the seismic response of a given polygon by representing the distribution of recorded seismic event magnitudes in the form of a histogram.

- It can be used to determine the network sensitivity (M min)
- It can be used to determine the Max expected size of event (M max)
- Other system properties like system stiffness can be deduced.

4.3.2.) **No.** Larger events are **under-**estimated by the fit. The fit is focused on representing events in the range -1.5<M<-0.5. The larger events (M>0) are the important ones that cause damage. (1)

4.3.3) The fit is up to the student but must be focused on a best fit to events in the larger event magnitude (M > 0.0). This ensure a more realistic prediction of larger damaging events. (3)



1 mark for sensible fit (i.e. above), 2 marks for calculation of GR relation.

GR fit (y=mx+c) or LOG(Number of events) = B x (Magnitude) + A

NB. Note that the y axis is a log scale.

Where

A = log(Number of events having magnitude > 0).

A = log 130 = 2.114 ***note that log is used – the y axis is a LOG scale*** ***(1)***

B = slope of GR fit line.

B = Δy / Δx = (0 – 2.114) / (2.2 - 0) = -0.91 (**NB slope is NEGATIVE)** **(1)**

GR fit equation :-	
Log(N(M))	**= -0.91 x (Mag) + 2.114**
Number of events(N(M))	**= 10^(-0.91 x (Mag) + 2.114)**

4.3.4) Very small events are not "sensed" by the system. The **sensitivity** of this seismic setup seems to lie at a magnitude range of about M_L = - 1.5 to -2.0. Events smaller than Magnitude minus 2.0 are likely not to be picked up. (2)

4.4. (2)

Along the lines of that on pg 249 of the handbook...

Seismic Event **(1)**

A seismic event is a transient earth motion by a sudden failure of rock. "Seismic event" refers to the failure of the rock and the resulting sudden release of energy. It need not be mining induced and it need not cause damage.

Rock burst **(1)**

A rock burst is sudden and violent disruption of rock within the excavation sidewalls in a mine. A rock burst is the consequence of mining activity and is often caused by or accompanied by a seismic event. **A "Rock burst" is a seismic event that causes damage**.

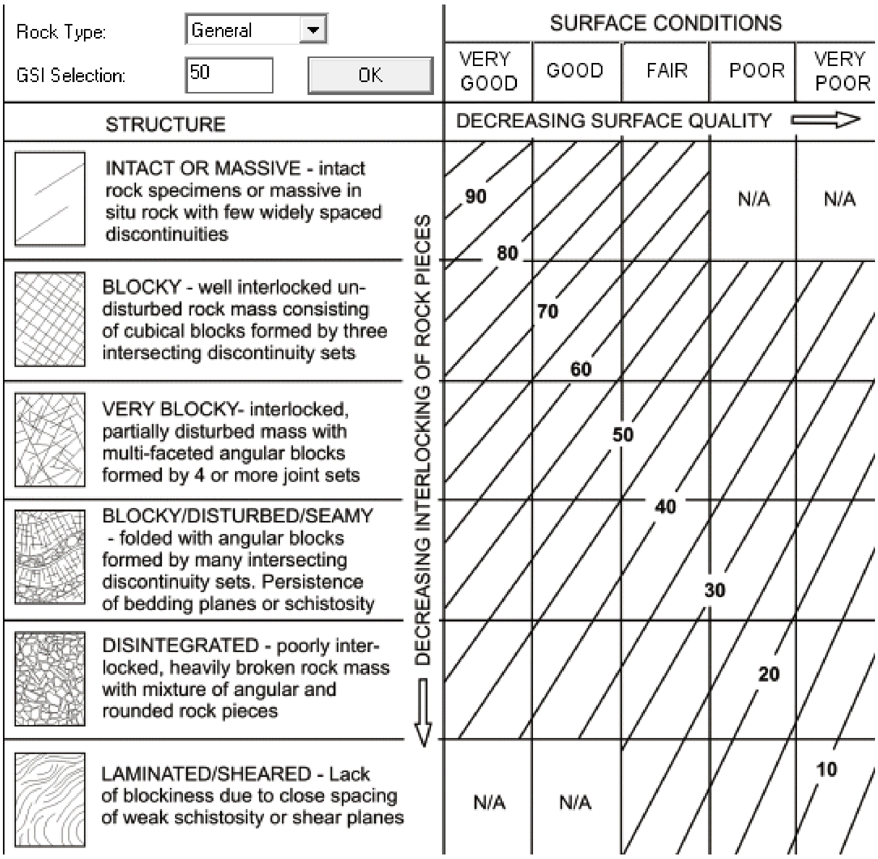
TOTAL : 20

Question 5

5.1. Any sensible discussions around the following (1 mark per fact)

a) Geological Strength Index (GSI) (any 2 comments on the GSi parameter) (2)

- Measure of rockmass competence devised by Evert Hoek
- Specifically devised for use in the Hoek-Brown failure criteria.
- GSi ~ RMR - 5 (RMR and GSi are closely related)
- The GSi method utilises **a visual assessment** to classify a rockmass according to its degree of "brokenness" and the condition of its joint surfaces. This is often easier to apply in the field.
- Range 0 - 100. 0 is very poor (soil), 100 is very good (no jointing).



b) Disturbance factor (any 2 comments) (2)

- Factor that accounts for rock disturbance due to **BLASTING**
- Range is 0 to 1
  - D = 0 refers to excellent quality controlled blasting or tunnel boring
  - D = 0.8 refers to poor blasting where the tunnel sidewalls are greatly disturbed by the blast.
- The Disturbance factor should NOT be applied to the entire rockmass - it applies to the excavation skin only.

c) mi **(2)**

- mi is a **material constant** (depends on the type of rock)
- mi is related to the frictional properties of the rock
- Range is approx. 5 to 35 (5 being for weaker rock like Chalk or some clays, 35 being for stronger rock like granite)

5.2. (3)

The H-B failure criterion is based on the assumption of shear type failure of a jointed rockmass. As such, it is not well suited for use in rockmasses at either of the **extreme ends** of the GSi scale. (1)

It must be used with caution

- in very competent / un-jointed rockmasses (high GSi) and, (1)
- very poor (almost soil-like) rockmasses with very low GSi. (1)

  Modifications have been proposed to cater for these extremes and can be traced in available literature.

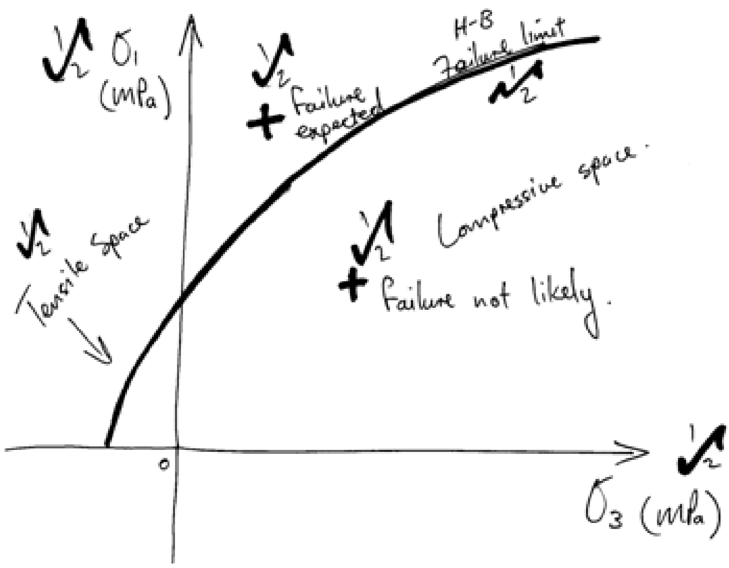
OR It must be used with caution (other acceptable comments)

- in Anisotropic rockmassess
- In very deep mining environments (some numerical modelling evidence exists to show that the criterion looses ability to accurately depict failure at great depths)

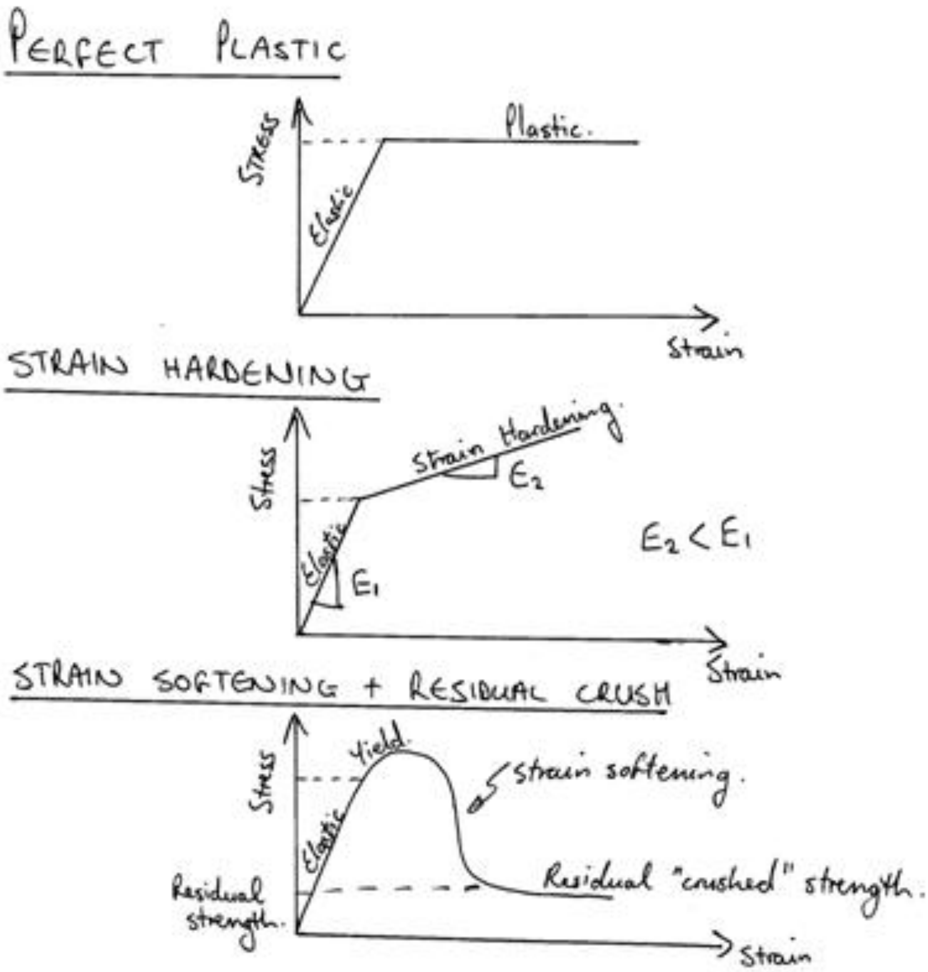
5.3. (2)

The Main Mohr-Coulomb equivalents are Cohesion (Co), friction angle (phi)

5.4. (3)



5.5. **(3)**



5.6. **(3)**

A basic discussion is required to show that the student understands how a failure criterion can be utilised to define the expected rockmass response (the stress strain relationship).

<u>For example:-</u>

A typical modelling program will assess the state of stress at a point of interest. A failure criterion like the Hoek-Brown or the Mohr-Coulomb can then be used to define whether or not failure is expected at this point in the modelled rockmass. Failure in modelling terms, is represented by a "non linear" and often user-defined stress-strain response.

If not failed (below the failure limit), then stress and strain are related by the elastic constants E and v. If failed (above the failure limit) then a simple stress - strain flow rule (like those presented in 5.5. above) can be used to define the rockmass response to further increases in modelled stress.

TOTAL : 20