Nr	Date	Author	Topic	Summary	Future work suggested/listed/questions
1	19-Mar-14	F Malan, J Napier	Literature survey, numerical modelling and seismic data analyses	It is an accepted practice in the RSA deep level gold mining industry to reduce the mining in an area that shows high seismic response to mining and it is generally accepted that this reduction in production also reduces the seismic response levels. It is important to distinguish between "volume" mining (m2 mined per month in an area) and the mining rate of a specific face (face advance per month). Historically the "volume of mining" has been adapted in a specific area with a reduce tion in seismic response. Various studies are listed that indicated the impact of "volume" on seismic response. The hypothesis is noted that that slower mining (face advance rate) will dissipate more energy in a stable manner through slip along discontinuities and forming of fractures and that the seismic energy levels will thus be lower. At the same time, the ratio between the large and small magnitude events (b-value) will also be affected as more small events will occur. Seismic data analysis indicated an exponential trend between m2 mined and number of seismic events, but no conclusive evidence could be shown that mining volume affects the b-value, seismic moment or seismic energy released through seismic activity. Napier and Malan (2014) presented a novel approach to include time dependent crushing of the material ahead of the mining face using a Limit Equilibrium Model where the ERR is re-interpreted by including explicit energy dissipation processes (fracturing and slip on discontinuities) by applying a strength decay model to materials.	Detail calibration of model will be required after extensive 2D model assessments so that behaviour of the model is better understood. The Clustering Index, as suggested by one literature study should be investigated further.
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2	25-Jun-14	F Malan, J Napier	Numerical modelling of mining face advance rate	2 Dimensional models were created and executed and initial trials indicate that 3D models will be more complicated. The strength decay model forms the basis of the LEM that potentially could test strategies such as preconditioning and panel face advance rate scheduling. The numerical model is based on DD boundary element technique. The initial models included a simple geometry in 2D with a 100m parallel sided panel at 100MPa virgin stress. Strength parameters were decayed for 24 time cycles and the face was advanced for 1.0m and then allowed for another 24 time cycles (1 cycle / hour). The normal stress distribution ahead of the face (fig 2) indicates a crushed, stress relieved zone that changes with time and which is a function of the time at which the reef is fractured, the length of the mining step and frequency at which a mining step is taken. Decay time is greatest closest to the face and reduces further into the solid (fig 3) while the strength parameter increases to full strength some distance into the solid (fig 4). Closure of the stope can be provided and indicate the model's ability to provide different closure profiles for different decay parameters (fig5) and suggested similar profiles to those measured by Malan in the past. Energy release increment is calculated and indicate that slower advances will decrease the E whilst slower decay rates will also result in increased E if the advance rate becomes too fast for the strength decay. LEM and Strength decay models are explained in appendices.	Extension of 2D model to 3D is planned. Other decay models to be evaluated and could include a driving stress decay model rather than half-life as currently assumed.
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3	05-Sep-14	F Malan, J Napier	Influence of mining rate when using de-stress mining as a method of pillar extraction	De-stressing a remnant to allow extraction is a method considered in industry. Since the area, whether above or below the remnant must be extracted at high stresses, mining rate is expected to be important. Idealised geometry is considered with a square mined out area with two square shaped remnants on VCR, no dip at 2000m depth, undermining one remnant on Libanon reef. Understoped remnant in 20 x 5m steps. Investigated effect of middling by varying the middling between 10m and 25m. Decreasing middling suggests lower APS when understoped, with stress transferred to Remnant 2, which was not understoped. Results suggest that 45Deg de-stressing rule must be used carefully as stress levels are still high. ERR as a measure of stress concentrations historically provided some measure of seismic risk. ERR on Libanon mining as it undermines VCR remnant shows increasing levels and peak just when the remnant is close to being completely undermined, but is reasonably low (keep layout in mind). ERR in remnant 1 on VCR is much higher when extracting the VCR remnant (undermined and not undermined on Libanon reef). ERR spike near end of remnant still exists. APS on VCR remnant as understoping occurs is shown as ever decreasing, but the rate of decrease is larger when mining the 2nd abutment, compared to 1st abutment. Suggest that this is why more problems are experienced during mining under 2nd abutment. Stress distribution changes as mining progresses and high stress levels (shear stress created) is induced between abutments towards the end of the understoping that could lead to seismic failure. Suggests that shear stress parallel to the reefs are also created and could affect shear along bedding and thus closure levels. Report includes underground observations as calibration and showed shear or mobilisation of bedding in orepass between reefs, unravelling of hangingwall due to reducing (possibly tensile) stresses. The impact of bedding planes was then considered as a mechanism to dissipate shear stress by using the 2D version of the software and placing a parting plane below the VCR remnant, half-way between the two reefs. When the plane is allowed to slip, energy increment increases. By adding crushed abutments, this level reduces but still suggest that bedding will increase energy release increment.	Shear failure between reef edges was not visible at UG observations but slip along bedding. Confirmation of this impact on energy release levels is important.

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4	21-Nov-14	F Malan, J Napier	Progress report on numerical modelling of mining face advance rate	Strength of the rock mass ahead of the face can be described by a simple LE model. Strength parameters of the rock decays once failure is initiated. Decay rate is based on half-life exponential relationship. Extension to 3D in this report. Strength decay is based on the distance to the mined out edge of any point P. Due to 3D layout, the shortest distance does not necessarily pass through collocation points at which strengths can be determined. By dividing the minimum distance path into equal length sub-intervals and providing a strength "age" to each point, this method can be applied. Used a simple layout with 4 panels, advancing A, B by 1,0m then C, D by 1,0m, etc. until all panels have advanced 10m. Fig 4 indicates length of decay times with elements closest to edge having largest decay time and points towards solid rock the shortest decay times. Stress results indicate zero stress in mined out, irregular stress peaks along faces which decreases as distance into solid increases. Stress peak is shown in Fig 7 as 11.4m ahead of face whilst closure graph shows closure in back area but also ahead of the current face position, i.e. compression of crushed materials. Energy release plot show peaks immediately when face advances which then decreases until next face advance occurs. Peaks decrease from the start of mining until about 30% of total advance, irregular peak values occur towards the end of the advance cycles and small energy increases occur randomly between face advances. Energy plotted for A, B and C, D panels separately indicate higher energy values for panels C, D. Related energy to seismic risk by Gutenberg-Richter b-value and derived relationship that links W energy to effective magnitude through empirically determined parameters A', A and b. Fig 11 plots magnitude against cumulative frequency from fig 9 results and indicate that results follow same power law as that between number of events and magnitude (Gutenberg-Richter). Noted that testing against actual data is critical. Plotting same relationship between energy reported for panels A, B and C, D separately, no real difference in power law results (b-values) can be seen (Fig11). However, it looks possible that differences would be shown for more significantly different areas / methods / sequences and is promising.	Mining rate in 3D layout, reef-dip inclusion, mining sequencing in Sequential Grid layout, evaluate remnant extraction methods, design of crush pillars, face pre-conditioning, effectiveness of backfill in controlling seismic release are all issues that can be evaluated. Inclusion of off-reef structures such as bedding, faults also appear possible but the need to calibrate results against actual seismic responses becomes critical. Actual mining area simulation planned with actual seismicity in an area that mined, then flooded and stopped mining is suggested.
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5	07-Mar-15	F Malan, J Napier	Numerical modelling of multiple panel layout	Several issues have been identified during the development of the 3D version of this LEM, including long computational times, 125 x 125 grid limitations, impact of coarse grids and shortcomings in the crush zone time dependent model. The study of the grid sizes indicated that larger grids decreased computational time as run time is a function of the areal extent of the layout and number of crush elements and the calculation of local confining seam parallel stresses. Confinement is calculated along the shortest distance between any point and the excavation edge and takes a long time. Lumping is suggested to solve this concern. The impact of grid size on energy released was evaluated using 2D of 2 panels using grid sizes of 2.0m and 0.2m. Fig2 shows closure profile obtained from two grid size runs, and show that closure profile is insensitive to the grid size. Stress profile for two grids follow same path but coarse grid does not show same peak profile (fig 2b) and thus underestimates the peak and affect the unaccounted energy results as shown in Fig 3 where 15.9MJ/m from coarse grid and 19.4MJ/m from fine grid results. Peak energy release is when the stress drop is maximum between two successive mining steps. 3D layout was trialled for panels mining towards a dip pillar. mining occurs over 6 months, grids are 2m and area included is 250n square. mining schedule shows mining of certain panels in Table 2 and in month 5, flooding stopped all mining. Energy release shown on Fig 10 and show large E in period where mining was stopped due to flooding. Fig 11 shows that majority of energy is released immediately after advance and that as time step continue, energy drops significantly, just as is normally experienced after face advance. LE model advances include the path of minimum distance between point P and mining edge as the 3D layout creates problems as certain faces mine and closet edge is not another point. Also is the energy release concentration after advance and may just be an input parameter result - the strain-softening model should be considered to slowly reduce the strength of the material after failure, rather than a brittle, immediate drop in strength after failure.	Implement a more general seam confinement model regarding the minimum distance for 3D simulations. Investigate strain-softening model. Evaluate off-reef capability of the model. Calibration studies are required.

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6	23-Aug-15	F Malan, J Napier	Num modelling of rate of mining and layout stability	Longwall layout simulated for impact on energy release increments. Simulated mining over 6 months, including one month when mine was flooded and no mining occurred. Each day was simulated by 10 time intervals and strength decay was set to 150 time intervals. Accumulated energy increments showed large increment immediately after stoping, then very low increments for the rest of the time intervals until next mining step. It suggests that seismic activity occurs immediately after face advance and although it is not necessarily incorrect. However, it questions the impact of input parameters that would give a different distribution. Current decay factor (lambda) is applied to MC strength parameters (m, sigmac, principle stress space - strength slope, material strength). The impact of friction angle decay on interface was also included. Tested variations in input parameters impact on results, including grid size. Grid sizes from 0.2m to 2m were applied for the crush zone, with no crushing of the other panel edge allowed to simplify interpretation of results. Several runs (01 to 04) provided where input parameters, decay parameter, friction decay, was varied and showed impact on energy increment is significant when both strength and friction decay is included in run. Suggested that either decay models are included but not both. Element size variations indicate large impact on results with smaller grids providing a smoother distribution with limited peaks. The LEM code was developed further to look at HB parameters rather than MC. Suggests that HB version is dependent on single material parameter only (A=f (m, s)). It is possible to calculate an equivalent MC failure slope m from A, which was determined from HB parameters m, s. Plotting comparisons from HB and MC parameters it is clear that results vary and that HB allows slower build-up of confining stress in the fractured zone (fig 9, 10) which will affect energy increments.	Strength decay model surely impacts on the energy release increment distribution with time intervals and should be confirmed. Investigate normalising that will make impact of grid size less significant. Novel solution procedure will be tested to solve equations and could be possible to consider non-linear solutions in which HB relationship is employed to define limit equilibrium residual strength and could speed up evaluations.
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7	06-Jan-16	F Malan, J Napier	Numerical modelling of rate of mining and layout stability	Expressing the energy released in a manner which is grid size independent was evaluated as was the sensitivity of the model to selected input parameters. Simple sequential grid layout was used for the assessment. Impact of the slope parameter (mi, m0, mf) is driven by strength vs confinement stress relationships shown in Fig1. When rock fails, strength drops immediately from intact strength to failed strength and then decays with time using half-life relationship. The role of the slope (m) and strength intercepts (at zero confinement) on crushed zone and energy increments were evaluated by determining a scaled fracture zone length (GAMMA) which showed that this length is dependent on friction co-efficient and the slope of the strength envelope m. Evaluated 100m span parallel side panel with different grids and indicated in Fig 2 that fracture zone profile is similar, but peak stress value is higher for small grid. By varying the strength slope m, it was shown in Fig 4 that as the residual strength slope decreases, the scaled fracture zone length increases. The stress drop from the intact strength envelope to the failed strength envelope affect the energy release increments. 3D model with panels A, B, C, D was simulated and applied residual strength envelope of 2, 4.5 and 7 (no stress drop between intact and failed at m=7). As difference between mi and mo decreases, the energy increments also decrease. When stress drop is greatest, the energy increment is greatest (Fig 7). Plots of closure and closure increments, as well as energy increments indicated a relationship between undissipated energy increments and closure increments suggesting that physical parameter such as closure can potentially be utilised to indicate seismic response. Effect of grid size (1m and 2m) and mining rate was simulated using a dip pillar layout and mining panels from one raiseline towards the dip pillar, where the mining rate was varied in consecutive months. Results indicate that fine grid suggests lower energy increments than coarse grids (Fig 14 - Fig 16) and Fig 17 shows that cumulative energy release per mined out area for the different mining rates is not significant. Cumulative energy per area mined for fine grid indicates that slow mining rate provides highest E/m2 result. Fig 19 plotted cumulative energy against time and indicate that slow rates have lower energy release rates per time. This suggests that planning should rather look at production within certain time limits than just area mined which means face advance should form part of a mine plan. Note that the grid size should not exceed the face advance distance (grid 2 > face advance 1m) in models.	Calibration of historical data required to substantiate face advance impact on energy release. Limitations include the areal extent that can be included into the model and the lack of calibration of the half-life parameter. The extension of the algorithm to compute triangular elements (compared to current square) and the look at off-reef processes will be addressed in future.

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8	10-May-16	F Malan, J Napier	Layered strata modelling	Importance of layered strata on possible stress, closure and energy available for release levels is assumed and investigated using 3D model. Alternatives evaluated include explicit layer modelling, transversely isotropic mediums and frictionless laminated models (FLM). FLM is very simple representation and must be used with caution. Explicit modelling is complex and require extensive run times. FLM (with varying thickness parameters) was compared to isotropic models and indicated sensitivity of results to thickness parameter t. Closure profiles and stress distributions appeared acceptable. Comparison on massive rock mass to explicit bedding modelling, indicated higher closure and peak stress levels for models that included bedding. Explicit and FLM indicated possible correlation of results. A special solution model has succeeded in reducing the run times on models.	Inclusion of Cohesive parameter in LEM model and impact on stress levels ahead of face must be investigated further. Test / compare FLM with explicit bedding behaviour
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9	16-Aug-16	B Okhuis	Model sensitivity to the presence of bedding	Using the 2D Texan models, model handling of bedding started in Jan 2016 as part of Study Project. The presence of bedding in the hangingwall of the stope impacts on the closure and stress profiles ahead of the mining face. An increase in the number of beddings or decrease in bedding plane spacings / bedding thickness increases stope closure and decreases peak stress ahead of the face. However, it results in a decrease in available energy to be released. The inclusion of bedding in models (gold mining environment) seems important when the impact of bedding shearing on closure profiles and energy to be released is of concern. The evaluation of the impact mining rate on the closure, stress and energy results indicated that faster mining rates increases closure, stress and available energy whilst slower advance rates decreases these parameters. Combining the bedding and advance rates indicates the importance of advance rates in a bedded environment.	Sensitivity studies for bedding plane friction angle / cohesion, error limits and iteration cycles to be conducted. The models to be changed to include bedding in footwall and extending the bedding ahead of the mining face. Including fault planes into the models will be evaluated with and without bedding. TRial FLM module and compare results.
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10	05-Sep-16	Jannie Maritz	Calibration of 3D LEM model with crush seam and time dependent mining	Digital mining plans have been gathered to commence with the calibration of the code version that still excludes the impacts of the issues reported in 2016 by Napier, Malan and also Okhuis. The aim of this modelling is to start a process whereby actual mining of a raiseline at the Khusasaletho Mine in the Carletonville area is simulated. The original plan to simulate the extraction of the Bambanani Mine shaft pillar in the Welkom area has been postponed due to the excessive run times and current size limitation of the code.	Run models to get regional stress levels. Apply stress levels as boundary conditions to a LEM model that evaluate the mining over a limited period of time. Derive the suggested available energy levels and compare with actual seismic activity recorded.
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11	15-Sep-16	F Malan, J Napier	Part A: Analytical model of pillar stress-strain behaviour	Derive average pillar stress-strain behaviours for strip and square pillars indicating softening or hardening behaviours. The dependence of the results on certain input parameters Q, M and β is shown. Dependong on these parameters chosen, the behaviour of the pillars can be estimated. This feature can be used as an individual pillar behaviour study or to calibrate against field data.	Selection of input parameters. Test on pillar field data at Manganese mines.
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12	15-Sep-16	F Malan, J Napier	Part B: Effect of mining rate in a coal mine	Historical work indicates development of high stress cloe to coal mine face and bursts. Several other codes used in past with varying success LA model, Muslim, 3DEC. Tested TEXAN with seam softening, FLM and time dependence features. Standard bord and pillar layout simulated in a particular sequence of pillar extraction at 500mbs whilst varying mining rates. Results indicate (1) differences in energy released as extraction progresses (number of pillars mined), (2) slow energy release between pillar extractions when mining rate is slow.	Mine each pillar in steps rather than "vaporising" each pillar at extraction. Require site specific calibration.