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Seismicity underground with particular reference to rockburst problems

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ABSTRACT: Underground structures such as mine stopes and shafts are continually affected by seismic elastic vibrations. Where these are large and/or sustained they may cause non-elastic motions leading to damage. During the current research program some rockburst mechanisms are highlighted, and applications of active and/or passive mitigation techniques are critically overviewed. Some attempts are made to explain rockburst phenomena in relation to local, mine induced and natural seismicity in Eastern Goldfields of Western Australia. It is emphasised that rockburst research should concentrate on improving the understanding of rockburst mechanisms and the recognition of seismic hazard zones. Advanced monitoring systems are required. New approaches and techniques are briefly discussed.

1 INTRODUCTION

Seismic events affecting underground structures are very diverse in their nature and their origin, and therefore depending on the type of the movement, type of the structure we deal with different and very often very complicated problems.

Briefly, complexity and interrelationship between various seismic phenomenas mostly affecting human activity are graphically presented in Figure 1.

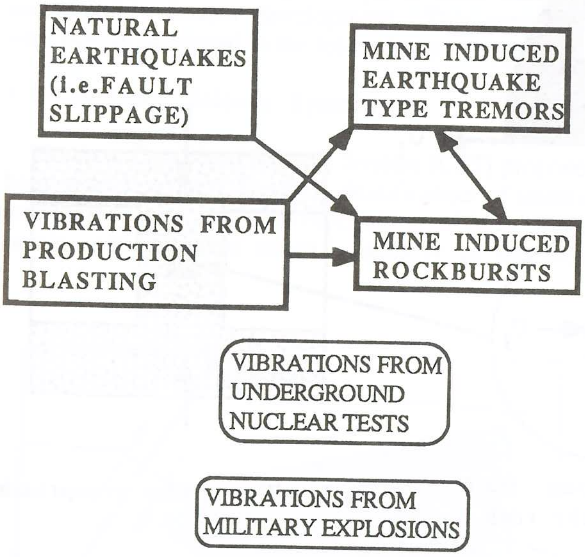


Fig.1. Chart showing interrelationship between various seismic events.

The above relationships are very often omitted in the course of many current studies, or the mechanism of mine induced and natural seismicity is not well known. As a result of such approach, often mine induced relatively significant tremors, (magnitude in Richter scale up to 5), are even not included in the statistics of the earthquake activity of the particular region. Mine induced tremors are often incorrectly considered by leading seismologists as 'not my parish'.

2 ARE SEISMIC EVENTS DANGEROUS FOR UNDERGROUND STRUCTURES OR NOT ?

Underground structures, especially in the mining environment are being continually affected by seismic elastic vibrations. Where these are large and / or sustained they may cause non-elastic motions, leading to damage. During assessment of any underground structure's resistivity to seismic event,the following should be realised;

* underground structures are not exposed to the 'public eye', therefore their seismic resistivity is often ignored,

* major problems occur where crossing of active faults by underground structure is unavoidable; fault slippage, tension (or compression) and associated seismic events as well as shearing of the structure must be considered,

* in an event of seismic activity, underground structures especially in the urban environment might be occupied by a significant number of people, therefore seismic resistivity of such structures should be of paramount importance,

* in modern urban environment boundaries between 'underground' and 'above ground' structures are not always clear cut (e.g. underground carparks and high rise buildings can form one integral unit), therefore the statement 'what is safe & what is not' is of limited value,

* seismic damages to high pressure underground gas pipes can result in gas explosion,

* because of the underground character, repairs are often costly and time consuming, especially in case of structures below the local water table,

* it must also be realised, that mine tremors, mine induced earthquakes or rockbursts are events occurring almost daily, creating real hazards,

* furthermore, due to the variety of factors, experience gained at any particular site is often of local value only, which explains contradictory results collected in the past by different researchers,

* in the mining environment, unwanted seismic effects are often associated with loss of high grade ore, time delays, costly repairs, damage to stopes and expensive equipment, loss of life,

3 PROBLEMS ASSOCIATED WITH ROCKBURST

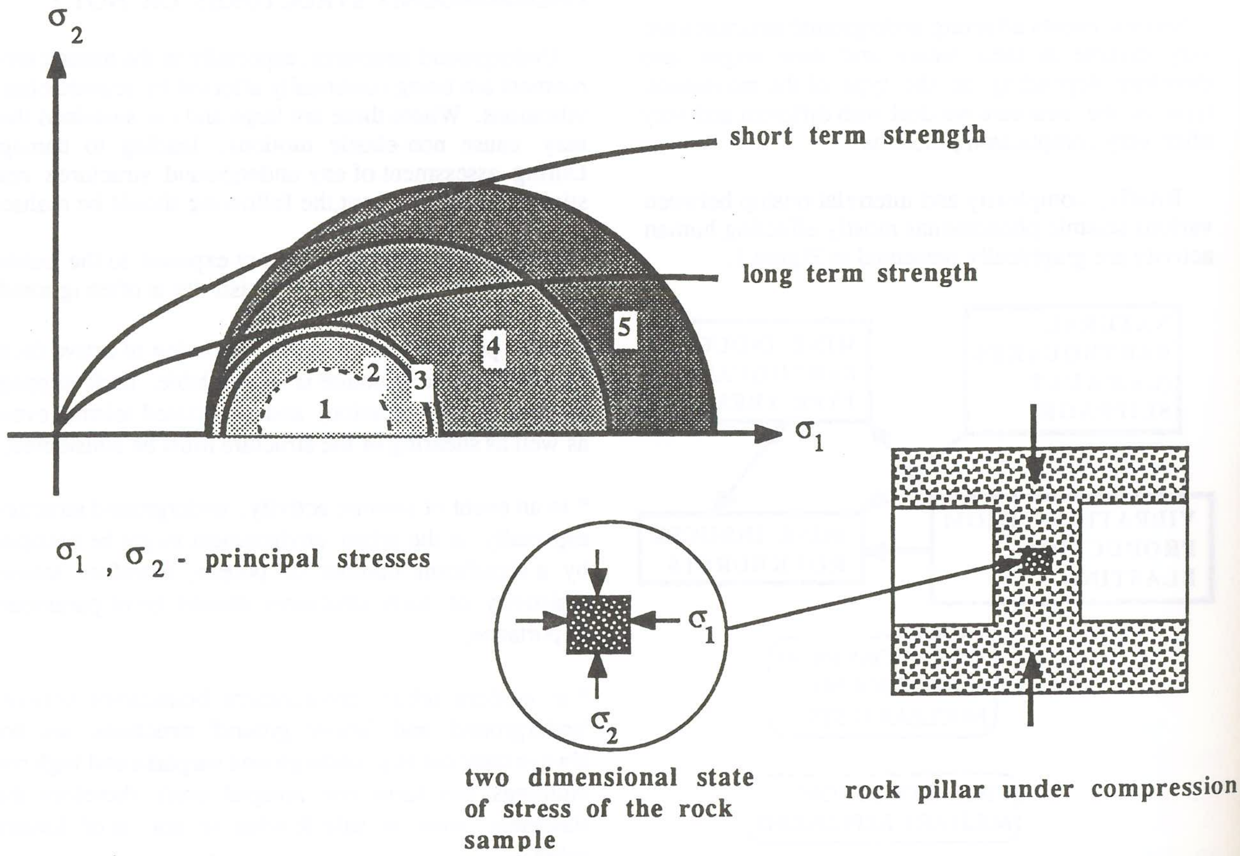
Rockburst can be defined as sudden breakage of rock formations accompanied by seismic energy release wave propagation. The state of stress and stability in which the rock formation might be can be presented graphically with help of the Mohr's circles in two dimensional system of coordinates, (Figure 2);

Despite significant effort undertaken by these researchers to explain rockburst phenomena in various countries, the following conclusion might be made;

* the majority of earlier studies did not include important parameters such as for example mining sequence, excavation rate, mine geometry or magnitude scale in which the event has been measured,

* experience gained at any particular site as mentioned earlier is often of local value only due to the various geological and mining conditions. Therefore, mechanisms of rockburst will almost always need to be analysed individually and methods well proven in other areas must be critically overviewed,

* instrumental experience gained by others as well as error / discrepancy analysis can be very valuable in the future projects.



1- in natural state,
2- safe, though less so than before,
3- in state of long term instability, but not dangerous,
4- possible failure, but should give warnings before failure,
5- rockburst,

Fig. 2. State of stress in the compressed pillar representing real mining environment.

Various mechanisms of rockburst have been analysed in the past by a number of researchers; (Cook et al.1966, Mc Garr et al. 1975, Hasegawa et al. 1989, Bawden 1993, Mendecki 1993). More comprehensive list of researchers and their work is included here in the References, see also Poplawski, (1993).

4 VARIOUS MECHANISMS OF ROCKBURST RELATED SEISMIC EVENTS

Selected various mechanisms of mine affecting and mine induced seismic events and rockbursts are graphically presented in figures 3 to 12. For clarity, only the schematic relationships are presented, without details or scale.

However, it must be emphasised here, that these possible mechanisms are not of equal importance, and such importance varies depending on the real situation on site. Moreover, various parameters,(e.g.encountered geological setting, new mining technique) can change significantly level of such importance during the mine life and hence, priority can be put in another area.

Mechanisms depicted in Figures 4, 6 & 8 probably need more attention. As a common practice so far mine seismologists often consider mine induced seismicity in terms e.g. triggered fault slippage or their efforts are concentrated on monitoring of microseismicity associated with various pre-rockburst mechanisms.

On the other hand, blasting and/or mining engineers consider blasting vibrations rather separately from mine induced seismicity. This involves simplified assessment of stope's resistivity to such vibrations, and often a single parameter such as ground Peak Particle Velocity is adopted as a safety level.

The new concept is proposed here, however at the current stage of knowledge it requires more attention and possibly further development. This concept is very briefly presented in the following paragraph.

4.1 Combined Seismic System.

The new Combined Seismic System (CSS) proposed here would include detailed identification of seismic mechanism, and therefore recognition of high stress/ /strain concentration zones, similarly to the most commonly adopted approaches, however, the proposed system would also incorporate the seismic vibrations caused by production blasts and influence of such vibrations upon existing natural fault / dyke system.

In other words, the possibility of triggering fault (dyke) slippage or thrusting by blasting vibrations should be investigated, (see Fig. 4, 6, 8), and if significant, such vibrations and their effects should be incorporated into the seismic system, (e.g. into the Integrated Seismic System, developed by Mendecki et. al., (1993), see also paragraph 6.1.)

The new concept is based on the assumption that if blast vibrations in certain circumstances can cause damage to underground stopes, (which has been well recognised throughout the world), and if changes in the stress/strain regime, (e.g. due to the intensive mining), can trigger dynamic fault slippage, blast vibrations can probably contribute to the overall dynamic behaviour of the fault. This blast induced dynamic behaviour of the fault can reflect on the mine development. It might also be emphasised here that mine induced seismic events such as rockbursts occur much more often than say natural earthquakes, and in turn, blasting takes place more often than severe mine induced tremors.

It must be said, that interrelations between natural earthquakes and mine induced seismicity have been investigated in various countries including USA and Canada, (Wong et al.,1989; Bicknell & Mc Garr, 1990; Wetmiller et al., 1990), but interrelations between blasting and mine induced seismicity lack worldwide attention.

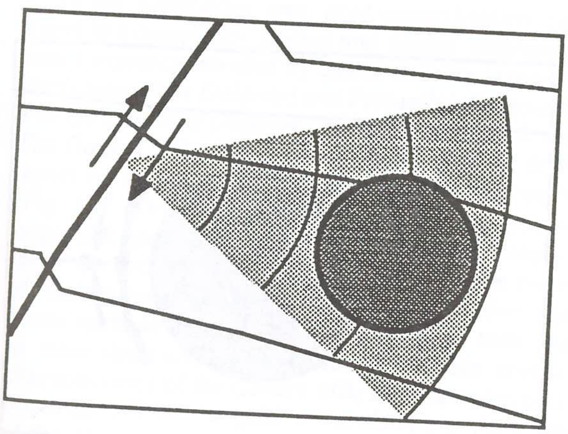


Fig. 3. Seismic waves generated by slippage on the pre-existing fault. Underground workings affected by such vibrations.

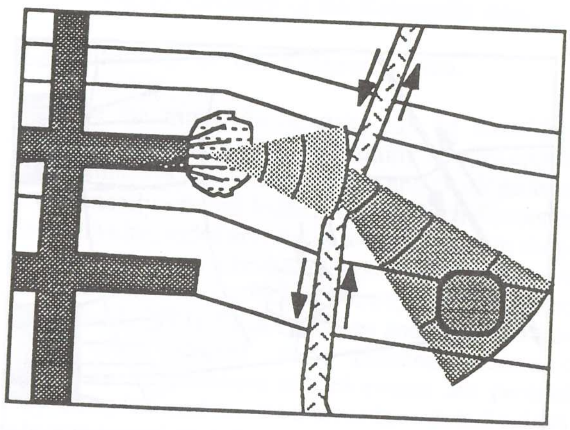


Fig. 4. Dynamic fault slippage caused by seismic waves generated by blasts. Such seismic wave created within fault, (compression or tension & shearing zone) can affect surrounding workings, (e.g. old, not well documented stopes).

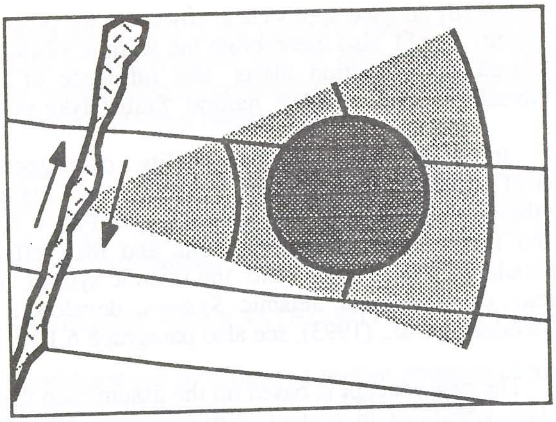


Fig. 5. Seismic waves generated by movements on hard rock intrusion, (e.g. quartz dyke).

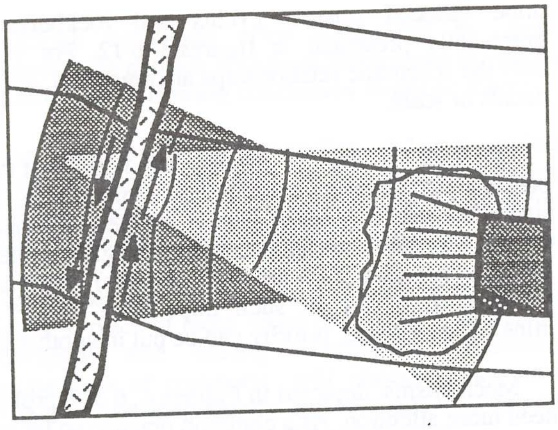


Fig.8.Vibrations caused by production blasts can trigger movements on hard rock intrusions and consequently, seismic waves influencing underground workings can be generated.

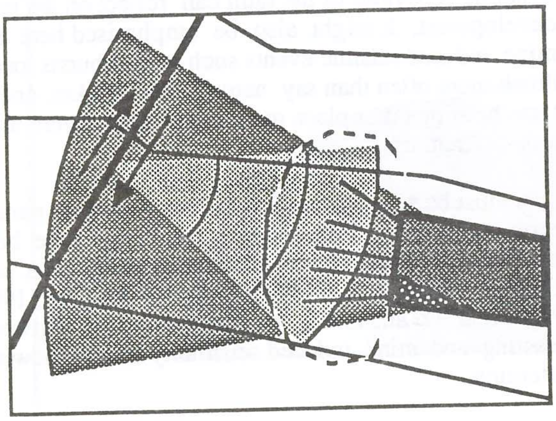


Fig. 6. Fault-slip type movement triggered by seismic waves generated by production blasts.

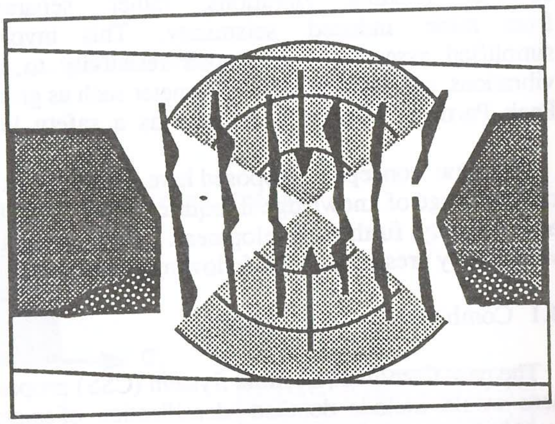


Fig. 9. Rockburst as a result of pillar failure.

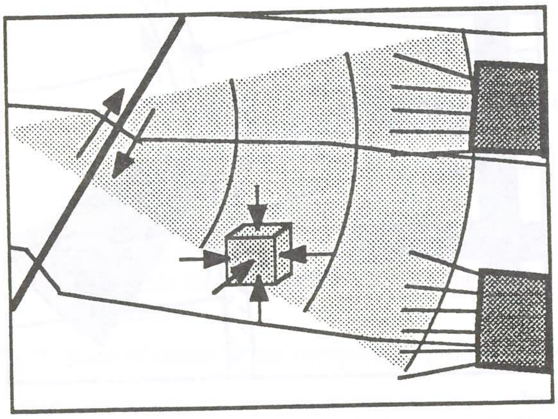


Fig. 7. Fault-slippage (thrust) triggered by rapid stress/ strain regime changes due to the intensive mining. Seismic waves generated in this way can affect underground workings.

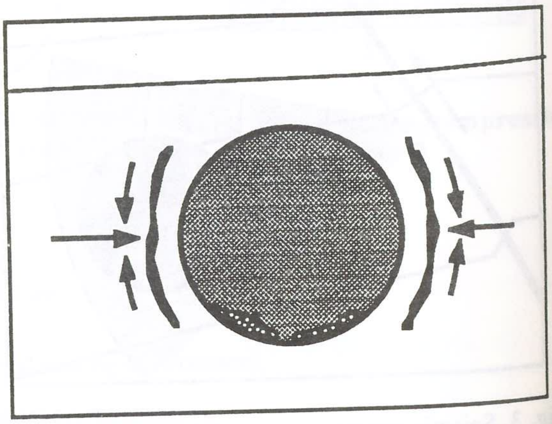


Fig.10. Rockburst manifested by sideway spalling and slabbing of tunnels walls.

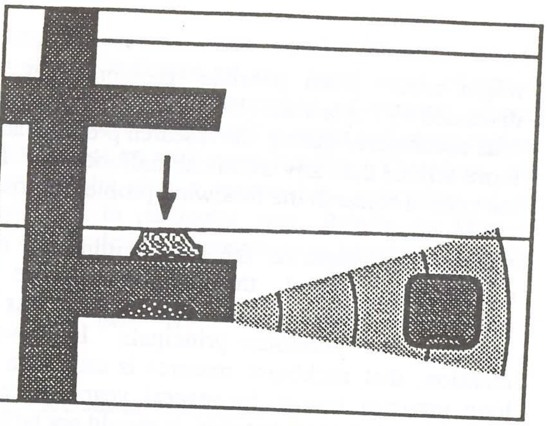


Fig. 11. Rockburst caused by remote falls of ground, (not a common event).

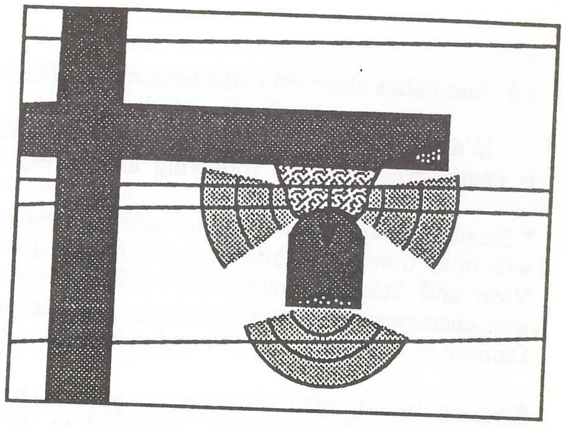


Fig.12. Seismic waves generated by roof collapse.

5 SEISMIC PROBLEMS OBSERVED IN THE EASTERN GOLDFIELDS, WESTERN AUSTRALIA

It has been proposed to investigate rockburst problems in the *Eastern Goldfields* area of Western Australia, where relationships between natural and mine induced seismicity are yet not well understood. The Kalgoorlie region has been seismically active since at least the late 1910's. As a result of subsequent seismic events, substantial damage was observed causing significant economic losses and sadly, a few fatalities. Seismic events in this region appear to be closely related to mining activity with most tremor locations being closely related to main mining areas.

5.1 Geology of the Kalgoorlie region.

In the Kalgoorlie area gold mineralisation can be found in a complexly faulted and folded sediment and basalt sequence intruded by quartz dolerite-layered sill, (the*Golden Mile Dolerite)* and Precambrian calc-schists. The *Golden Mile Dolerite* is overlain by black shales. The *Golden Mile* lodes occur in such basalt - dolerite layers on a tight, south plunging *Kalgoorlie Syncline*, (Fig. 13). This Syncline appears to be the most important geological formation in this area. Relatively large orebodies in the area indicate that the systems of underground channels were formed within shear zones such as cross-folds. Mineralisation took place in these shear and crack zones. Favourable chemical characteristics of the *Golden Mile Dolerite* also played important role in the gold mineralisation. As a result of the above processes, high grade pipe-like orebodies are intersecting fractures and intersecting shears. There is a significant amount of lodes in the underground space. The width of the lodes varies from a few centimetres to about 30m, and lengths of up to 1000m have been exposed. The net effect of the complexity of the lode system is that many mineable ore positions are masked by fault offsets or lode branching, (Ho, 1984; Reed & Askew, 1984; Elevatorski, 1988).

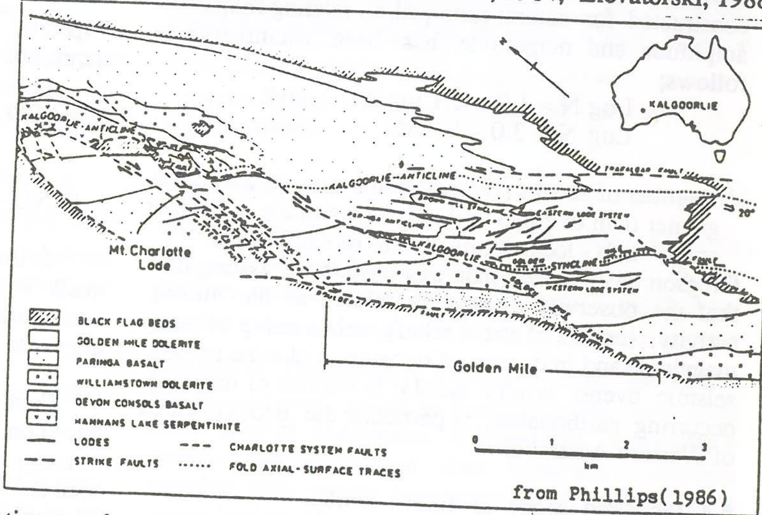


Fig.13. Geology of the Kalgoorlie area.

5.2 Seismicity of the Kalgoorlie area.

Because the main ore deposits can be found in the system of conduits and cracks,mining implies crossing the existing system of faults, shear and crack zones and geometrically various lodes systems. Such discontinuities and veins, lodes and dykes were reported in the past by number of researchers and mine managers as areas of high seismic risk, (see also Lee, Beer & Windsor, 1990; Auld, 1993). Such crossings and highly stressed pillars often caused mine induced tremors or rockbursts. Mechanisms of such events are probably very complex and must be investigated individually. It is anticipated that the system of quartz veins, lodes and particularly *Kalgoorlie Schist* and three major faults, *(Maritana, Reward and Charlotte)* require to be analysed in the light of focal and regional seismicity.

5.3 Anomalies observed in the Eastern Goldfield area.

In the *Eastern Goldfields* area observed seismicity is characterised by the following anomalies;

* Small amplitude values are not necessary associated with mild tremors. Example: tremor recorded at Lake View and Star Ltd. mine, (June 1965). Strong tremor was characterised by the relatively small amplitude. Damage to underground workings has been recorded.

* Strong tremor often did not cause any damage at all. This fact can be probably attributed to the local geometry of the stope and can be related to the type of rock support.

* Instrumental evidence and reports of damage locate events within the mined area, suggesting that the events are mine induced. Some parameters however are common with natural earthquakes. Gregson, (1993) showed that the statistical relationship, (usually constructed for natural earthquakes) relating frequency-amplitude and magnitude has been established as follows;

$$\text{Log } N = 1.9 - 1.1 \log A \quad \text{and;}$$
$$\text{Log } N = 3.0 - 1.1\, M_L \quad \text{where,}$$

N-number of shocks per year with measured amplitude greater than or equal to A, M_L - magnitude in Richter scale; a, b - local parameters to be established.
Gregson also stated, that that despite the assumption that the observed events are related to the mining activity, (results of stress relief), relationship between magnitude and frequency of occurrence of mine induced seismic events is very similar to regions of naturally occurring earthquakes, in particular the Brookton area of Western Australia.

5.4 Proposed scope of future work.

It has been proposed at some stage to investigate more closely seismicity in the area to establish a relationship between mine induced and natural seismicity. This would also enable better understanding of the rockburst phenomena. Consequently, optional mining technique, (e.g. mining sequence, support adopted, etc.) would probably mitigate rockburst hazard in both active and passive way. This would probably require installation of more sophisticated instruments, because at the present time a single, uni-directional transducer does not provide reliable information. New innovative system developed in South Africa ('ISS'), or more traditional *Kelunji* system developed in Victoria might fulfil such task. Brief description of the South African system is given in the next section.

5.5 Problems encountered during the present research.

During the course of any research, very often unexpected, time and money consuming problems might arise. Such possible problems are briefly discussed by Poplawski, (1993). However, real difficulties encountered during the research program are often more serious than any technical malfunctions. During the current research the following problems arose;

* personel changes on the 'top' (within the mining companies) created the situation where new management is not interested in research in this area as much as the previous principals. It is worth to mention, that rockburst research is usually a rather long program lasting for several years, therefore if planned and then undertaken, it should not be affected by sudden change in attitude or a bad mood.

* lack of funds, or unwillingness to provide sufficient funds for this purpose, as approx. $50 000 is required for the locally manufactured instrumentation,(in South Africa approx. 20 mln US $ have been already spent).

* mine induced seismicity seen as a public liability,

* specific philosophy adopted, therefore until fatalities occur, not much can be done,

* 'MABO' dispute ?

6 INNOVATIVE SEISMIC SYSTEMS

In the recent years significant progress has been made in seismic instrumentation, monitoring techniques, data collection and elaboration. Two systems appear to be the most innovative and reliable so far.

First system significantly developed in Canada is based on seismic tomography, where the stress-strain-velocity model enables identification of highly stressed seismic prone areas. It also allows identification of rockburst mechanisms and gives some ideas on it's prediction, (Young et al. 1989, 1990; Bawden, 1993).

Other system called Integrated Seismic System (ISS) is based on a new approach developed in South African deep gold mines, (Mendecki et al., 1993). Basic principles of this system are presented below.

Other methods such as Microgravity Monitoring, (Fajklewicz & Jakiel,1989), and Electrical Resistivity Method, (Stopiński & Dmowska, 1984), despite reported successes in rockburst studies, need also to be further developed.

6.1 Integrated Seismic System.

Main principle of the system is based on the fact that Richter scale, Seismic Energy alone, or Seismic Moment alone are not good descriptions of the rockburst potentials. It is proposed, (Mendecki, 1993), that the ratio of Seismic Energy to Seismic

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