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SURVEY OF SOUTH AFRICAN SEISMIC SYSTEMS

MINING RESEARCH LABORATORIES

SP86-10E

Canada

SURVEY OF SOUTH AFRICAN SEISMIC SYSTEMS

By

Dr. W. Bawden

Mr. F. Kitzinger

CENTRE DE RECHERCHE NORANDA

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FOREWORD

Canadian underground mines have had a long, and sometimes painful, history of rockbursting. The safety of Canadian miners depends, in part, on a continuing study of the rockburst problem and the potential for alleviation. A pivotal issue in this study is rockburst detection, location and characterization. The current thrust includes improving source location methods, wave form analyses, and circumventing spurious information from stray vibrations caused by mining operations.

The Department of Supply and Services, on October 11, 1985, awarded to the Centre de Recherche Noranda a contract to develop a state-of-the-art mine seismic monitoring system for rockburst detection in Canadian mines. The $321,000 contract will provide, by October 15, 1987, a mine-tested prototype seismic system suitable for general fabrication. The system under development is intermediate to present mine microseismic monitoring systems and to the national seismic network.

A fundamental principle guiding efficient research is that unnecessary duplication must be avoided. In strict adherence to this principle, the contract required an exhaustive review of available information on mine seismic studies, both domestic and international, prior to proceeding to the conceptual equipment design stage.

Because they are the world leader in this technology, part of this review included a study of South African mine seismic systems and practices. It is only necessary to briefly describe the South African mining industry rockburst problem to appreciate the impetus that impelled this leadership. Within a network of the world's deepest mines, they employ 400,000 miners. Rockbursts account for about 28% of their mine accident 'fatality rate of approximately one per thousand per annum'.

The Ontario record, by comparison, shows rockbursts to cause about 3% of all mining accident fatalities; a twenty-five fold difference! This very significant problem has led the South Africans to devise new and different ways of monitoring rock noises. The Noranda staff visited South Africa for direct discussion with their experts on mine seismic systems, and to acquire first hand knowledge of advances and current difficulties.

Upon reading the visit report, it became evident that it contained considerable general information of value to anyone dealing with potential rockbursts. It was, therefore, decided to make the report available to the Canadian mining industry by issue of this special CANMET report.

The staff of the Centre de Recherche Noranda responsible for carrying out the survey and visit, Dr. Bawden and Mr. Kitzinger, are to be congratulated for the quality of the survey and the report. At the same time, I would like to express my appreciation to those whose cooperation made the success of this survey possible.

John E. Udd

Director

Mining Research Laboratories

AVANT-PROPOS

L'historique des mines canadiennes est parsemée d'événements pénibles ayant pour origine les coups de toîts. La sécurité des mineurs canadiens repose en partie sur l'étude approfondie des coups de toît et des moyens à prendre pour solutionner le problème. Cette étude a pour objectif primordial le détection, le repérage et la caractérisation des coups de toît. La poussée actuelle de recherche dans ce domaine englobe les méthodes de repérage des sources d'énergie sismique, l'analyse des formes d'ondes et une méthode pour faire échec à l'information douteuse provenant des vibrations dispersées.

Le 11 octobre 1985, le Ministère des Approvisionnements et Services a passé un contrat avec le Centre de Recherche Noranda en vue de développer un système de surveillance sismique avancé pour la détection des coups de toît dans les mines canadiennes. Grâce à ce contrat d'une valeur de 321 000 $, il sera possible de compléter la mise au point, dès le 15 octobre 1986, du prototype d'un système sismique ayant fait l'objet d'essais miniers et susceptible d'être fabriqué sur une échelle commerciale. Le système en voie de réalisation se situe à mi chemin entre les systèmes de surveillance microsismique actuels et le réseau national de surveillance microsismique.

Un principe fondamental sous-jacent à toute activité de recherche se lit comme suit: "Point ne cherchera à réinventer la roue". En conformité avec ce principe, il importait d'effectuer, dans le cadre de ce contrat, une revue complète de toute l'information disponible relative aux études sismiques effectuées dans les mines à l'échelle nationale et internationale avant de procéder à l'étape de la conception et de l'élaboration de l'équipement.

La suprématie de l'Afrique de Sud dans ce domaine étant reconnue dans le monde entier, une partie de l'étude est consacrée aux problèmes auxquels ce pays doit faire face et aux pratiques minières qui y sont utilisées. Un bref aperçu des problèmes que suscitent les coups de toît au sein de l'industrie minière sud-africaine permet d'apprécier toute la portée de la direction positive de ce pays. L'Afrique du Sud possède un effectif de 400 000 mineurs qui exploitent un réseau minier comprennant certaines des mines les plus profondes de la terre. Environ 28 % de tous les accidents mortels (approximativement un millier) qui se produisent annuellement sont causés par les coups de toît.

Comparativement, les dossiers de l'Ontario indiquent que 3 % de tous les accidents mortels qui surviennent dans les mines résultent des coups de toît! ce qui signifie un rapport de 25 à 1. Cette question épineuse a poussé les Sud-Africains à rechercher des techniques nouvelles pour détecter les bruits émanant des masses rocheuses. Le personnel de la Noranda a effectué une visite en Afrique du Sud afin d'étudier sur place, en compagnie d'experts du pays, les systèmes de surveillance sismiques et d'obtenir des renseignements sur les progrès réalisés et les problèmes non résolus.

Une lecture du rapport de cette visite suffit à nous convaincre de l'importance et de la valeur de l'information considérable qu'il renferme pour quiconque s'intéresse aux problèmes découlant des coups de toît potentiels. Par conséquent, le rapport sera mis à la disposition de l'industrie minière canadienne par le truchement de la publication du présent rapport spécial du CANMET.

Les membres du Centre de Recherche Noranda qui étaient responsables de l'étude d'ensemble et de l'organisation de la visite, M. Bawden et M. Kitzinger, méritent des félicitations pour la qualité de leurs travaux. Je désire, par la même occasion, exprimer ma reconnaissance au personnel des organismes et instituts miniers dont la précieuse collaboration a contribué à la réussite de cette étude.

John E. Udd

Directeur

Laboratoires de recherche minière

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SEISMIC SYSTEMS

By

Dr. W. Bawden and F. Kitzinger

1. Meeting with Dave Ortlepp, of Anglo American Corporation, Dec. 1st, 1985, Johannesburg

Mr. Ortlepp gave an overview of gold mining in South Africa and described the key organizations and personnel involved in the development and operation of seismic systems. There are three key gold mining areas in South Africa, the first is near Johannesburg, the second is known as the Klerksdorp Area, the third is the Orange Free State, (usually abbreviated OFS), and the local town is Welkom. The main gold mining companies in South Africa are as follows:

Rand Mines
Anglo American Corporation
Gencor
Anglo Transvaal Limited
Goldfields of South Africa Ltd.
Johannesburg Consolidated Investments (JCI)

Along with the mining companies, the key organizations involved in South African microseismic rockburst research include the Bernard Price Institute for Geophysical Research (BPI), and the

Chamber of Mines of South Africa. The Bernard Price Institute is associated with and located at the University of Witswatersrand with Dr. Rod Green as the main researcher. The Chamber is a general research institute funded by the Mining Industry of South Africa.

The workforce involved in mining in South Africa number some 500,000; approximately 400,000 of these men work underground, and most of these are black workers. Fatality rates in South African mining averages out at roughly 1 per 1000 underground workers per annum. Rock related problems account for roughly 55% of the fatalities and one half of those are associated with rockbursts.

The week prior to our arrival, a rockburst occurred at the East Rand Proprietary Mines Ltd. near Johannesburg. The burst was a magnitude 3.5 Richter and some 17 men were killed. The particular area where this burst occurred has surprised the South African scientific staff as they had not believed that that area was in danger of such a large magnitude event. Dave Ortlepp claims that Anglo American has evidence that with high enough stresses, they can generate their own mining induced faults with up to 2,000 square meter fault areas. On an industry-wide basis, the gold mining productivity is roughly one ton per man shift per day.

2. Visit To The Western Deep Levels Mine, Owned By Anglo American Corporation - Dec. 3rd, 1985, Carletonville

The Western Deep Levels Rock Mechanics Department is divided into two arms; a research arm and a services arm. The rock mechanics research arm has three functions as follows:

-Rockburst Research,

-Rockburst Prediction,
-Computer Facilities.

The rockmechanics services group is headed by a Regional Head, Mr. Dave Arnold. Each of the three shafts, then are headed by a Section Head, who is backed up by a Rock Mechanics Officer and two Strata Control Officers. All of the Section Heads report to Mr. Arnold. Western Deep Levels, as with all of the deep gold mines, is mined by a Long Wall Mining Method. Each mini-Long wall is broken up into three roughly 35 meter panels. The productivity is aproximately 50 tons per panel per day. The Western Deep Level seismic system consists of a macro system or mine-wide system and 5 micro systems.

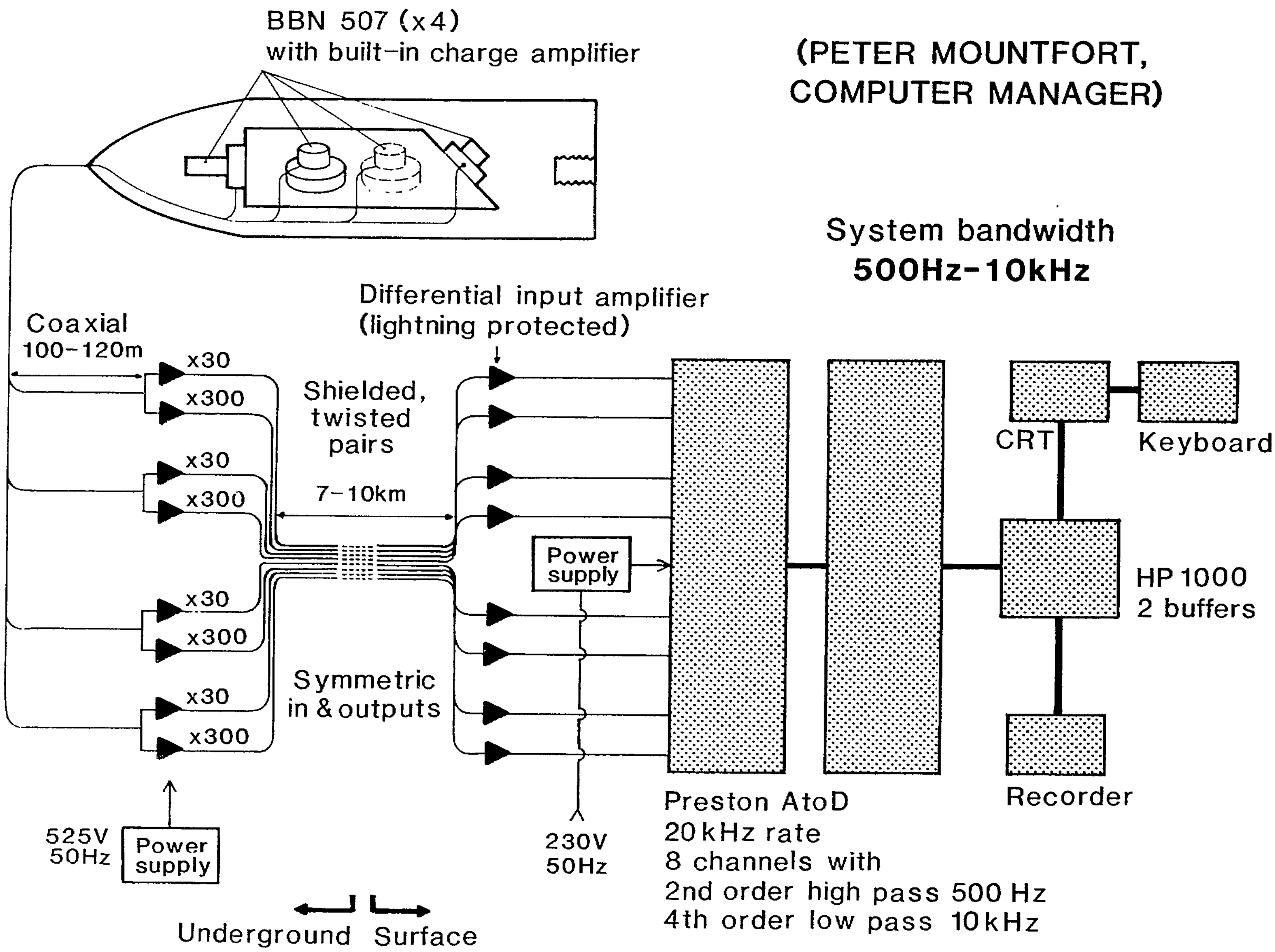
2.1 Microseismic System Description, Peter Mountfort, Computer Manager

There are five micro systems presently active at the Western Deep Levels (Fig. 1). Each micro system consists of a single triaxial sensor covering roughly a 200 meter radius area. The micro-seismic systems are designed to pick up events ranging from -3.5 to 0 Richter and are designed to operate between 500 Hz and 10 KHz. Model BBN-507 piezoelectric accelerometers, with built-in charge amplifiers* are used in the triaxial sensors. The housing to hold the three accelerometers for the triaxial units was designed and built in-house by Anglo American (Fig. 2). They have found that their triaxial units have a resonance problem at approximately 5 KHz. This was found through underground observation. The units have not been tested on a shake table. They initially attempted installing the triaxial geophones by simply sanding them into the borehole but found that coupling was not sufficient. They then enclosed the triaxial sensor in a steel

*BBN Instruments Corporation,
50 Moulton Street, Cambridge, MA. 02138 (USA)

Figure 1.

MICROSEISMIC SYSTEM, WESTERN DEEP LEVELS LIMITED



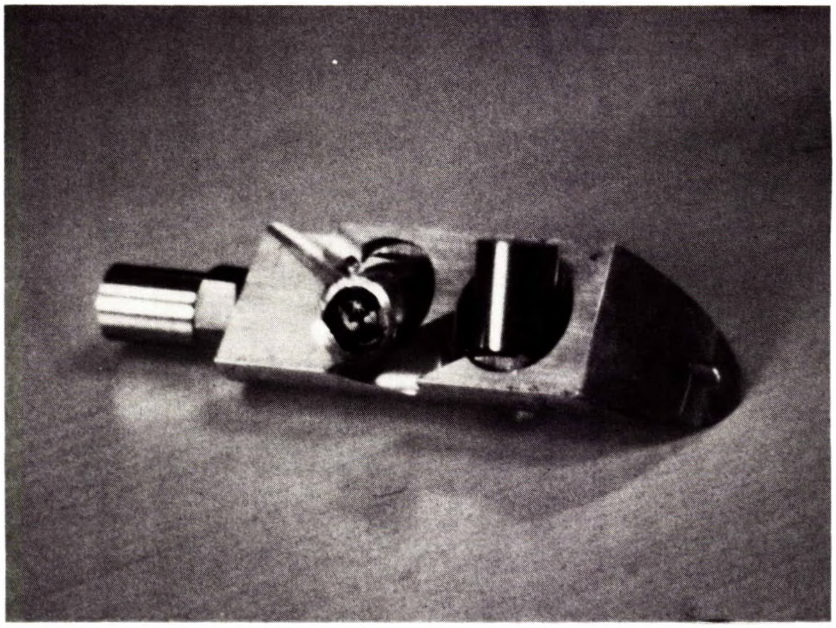


Figure 2. Piezoelectric accelerometers in triaxial mounting.

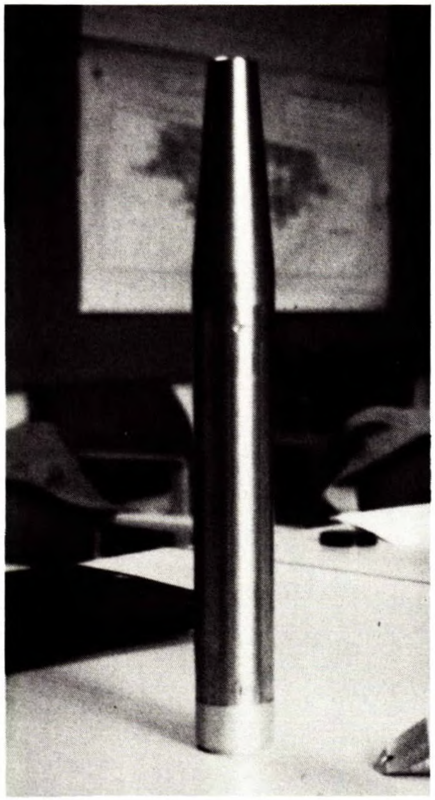


Figure 3. Stainless steel housing for triaxial sensors.

pipe housing (Fig. 3) and grouted this into the boreholes. The BBN 507 sensor itself resonates ap approximately 20 KHz with a +3 decibel point at approximately 12 KHz.

Signals below 500 Hz are rejected by a 2nd order high pass filter. This is done in order to cut out any mine noise. The fourth order anti aliasing filter limits the high end of the spectrum to 10 KHz. Analogue transmission is used, two amplifiers are provided for each axis, one is a low 30 X gain, the other a high 300 X gain giving a factor 10 difference in gain. This is used to get around the dynamic range problem. The A to D converter is used to determine if the high gain channel is clipped. If this is so, then the signal from the low gain channel must be accepted.

Anglo American claims that they are not able to get adequate frequecy response using the log amplifier system. The amplifiers being used were purchased in South Africa. The amplifiers are located at the collar of the borehole and in fact they could be located more than 100 meters away with negligible signal degradation. Shielded twisted pair cabling is used throughout the mine, noise is not a problem on the high frequency side and low frequency noise is filtered out due to the filtering below 500 Hz. 525 Volt AC power is supplied underground. The sensors are cemented into the holes using a straight forward cement grout. The triaxial sensor additionally uses a fourth sensor set at roughly 57 degrees to all of the other three sensors in case one of the orthogonal sensors ceases to function. The objective of the system is to parameterize events from the signals and then only store the parameters. The signal traces are integrated to obtain velocity. The sum of the squares of velocity is then used to obtain energy. Location of the events are done by PS Wave separation. Direction is obtained by P Wave polarization. P Waves are picked by an arbitrary threshold, which will be discussed later.

Following picking of the P Wave arrival, the P Wave is subtracted out so that a pure S Wave can be determined. Once the magnitude of the S Wave has been determined, the S Wave arrival time is picked. In-situ velocities are not well calibrated in the Western Deep Level Mine. In local areas, they can sometimes be correlated with particular features. The sensors are generally put about 200 meters ahead of the face. The face then moves toward the sensor. When the face reaches approximately 50 meters from the sensor, it is very difficult to separate P and S arrival times. The signal is digitized at the computer, it is rectified and summed to pick events. A digital comparator in the analogue to digital converter is used to do this. The signal is digitized at 20 KHz rate.

Two buffers are used in the computer memory to handle the incoming data. Once the event has been determined, parameters are calculated and stored. Events typically last about 50 milliseconds. The microseismic system at Western Deep Levels, therefore, only captures 50 milliseconds of data. With their PS separation, typically, this results in about 200 meter radius that the triaxial sensor can effectively watch. Their experience is that beyond about 250 meters, high frequency signals are filtered out. It takes generally 1 to 2 seconds to calculate the required parameters.

Thresholds are set to obtain a few hundred events per hour. System flooding occurs following blasting, and after large events, when the aftershocks overload the system. They also store the power spectrum with 32 points. Originally, a 64 point Fourier transform was done on the P Wave, however, this was later changed to 32 point FFT using the S Wave. They find that this generally gives more uniform results. Each triaxial sensor is fed to its own HP 1000 mini-computer. Twisted pair cabling is used all the way to the A to D converter and then into the HP 1000. Lightning protection is used on the cabling. Each 15 minutes, a complete trace is written to disk to check the system.

The method of picking P Wave arrival time is as follows: first, the three channels are rectified and summed, then the amplitude of the P Wave above the background noise is determined. Once this has been determined, the P Wave arrival point is taken as approximately 10% of that arrival amplitude. The ratio of the amplitudes as seen by the three sensors is then used to determine the incident angle of the wave. This is calculated as an azimuth and altitude, i.e., two angles, one in the horizontal plane and another in the vertical plane.

A similar picking procedure is used for the S Wave arrival times. Often the S Waves are very small. The procedure used at Western Deep Levels is to first look for the S Wave peak and the greatest area. Once this has been selected, the first 10% of this wave amplitude is used as the S Wave arrival. They claim to be able to see small S Wave splitting but do not yet know how to auto extract this. They noted that drilling noise comes through very clearly and looks very similar to a microseismic event. Very high frequencies are read if the drill is close to the triaxial sensor. The geophones for the microseismic system are installed in 30 meter deep boreholes. This is done to get away from fractures and reflections due to the mined-out areas. The final data is plotted in the following format:

- Corner frequency versus time,
- Event rate versus time,
- Average log energy versus time, and finally
- Log energy divided by corner frequency versus time.

They are gradually building an empirical data base for the Western Deep Levels and are experimenting with attempts to predict rockbursts in real time. They are presently trying to predict oncoming bursts at 8:00 P.M. and 4:00 A.M. for the next 8 hour shift respectively.

The prediction technique is to use event rate and average event energy. If the event rate builds rapidly, and does not fall off following blasting, this is assumed to be giving a warning that the panel is becoming dangerous. Waveform analysis is used to pick the arrival times in order to obtain better locations. Most events at Western Deep Levels are tied to geologic structure of some kind.

2.2 Macroseismic or Mine-Wide Network Description, Peter Mountfort, Computer Manager

The mine-wide system uses thirteen triaxial velocity gauges spread over the complete area of the mine, and one surface vertical single axis gauge for energy determination (Fig. 4). Geospace HS-J velocity gauges are used*. The natural frequency of the gauges underground are 4.5 Hz and have a moving mass of approximately 5 grams. The surface geophone resonates at 1 Hz. Three geospace HS-J units, two horizontal and one vertical, are mounted together to form a triaxial unit. They have had problems with the very low frequency sensors. They have found these to be very sensitive and to cease functioning after some time. They do not, at this point, know why. The 4.5 Hz sensors are found to be the most sensitive. The highest frequency signal normally observed by the macroseismic system is a few hundred Hz. Amplifiers are placed at the hole collar. In the mine-wide system, only larger events, generally at considerable distance, are picked up. The high frequency portion of the signal will not propagate to this distance and it is claimed, therefore, that there is no reason to go to the expense of using accelerometers.

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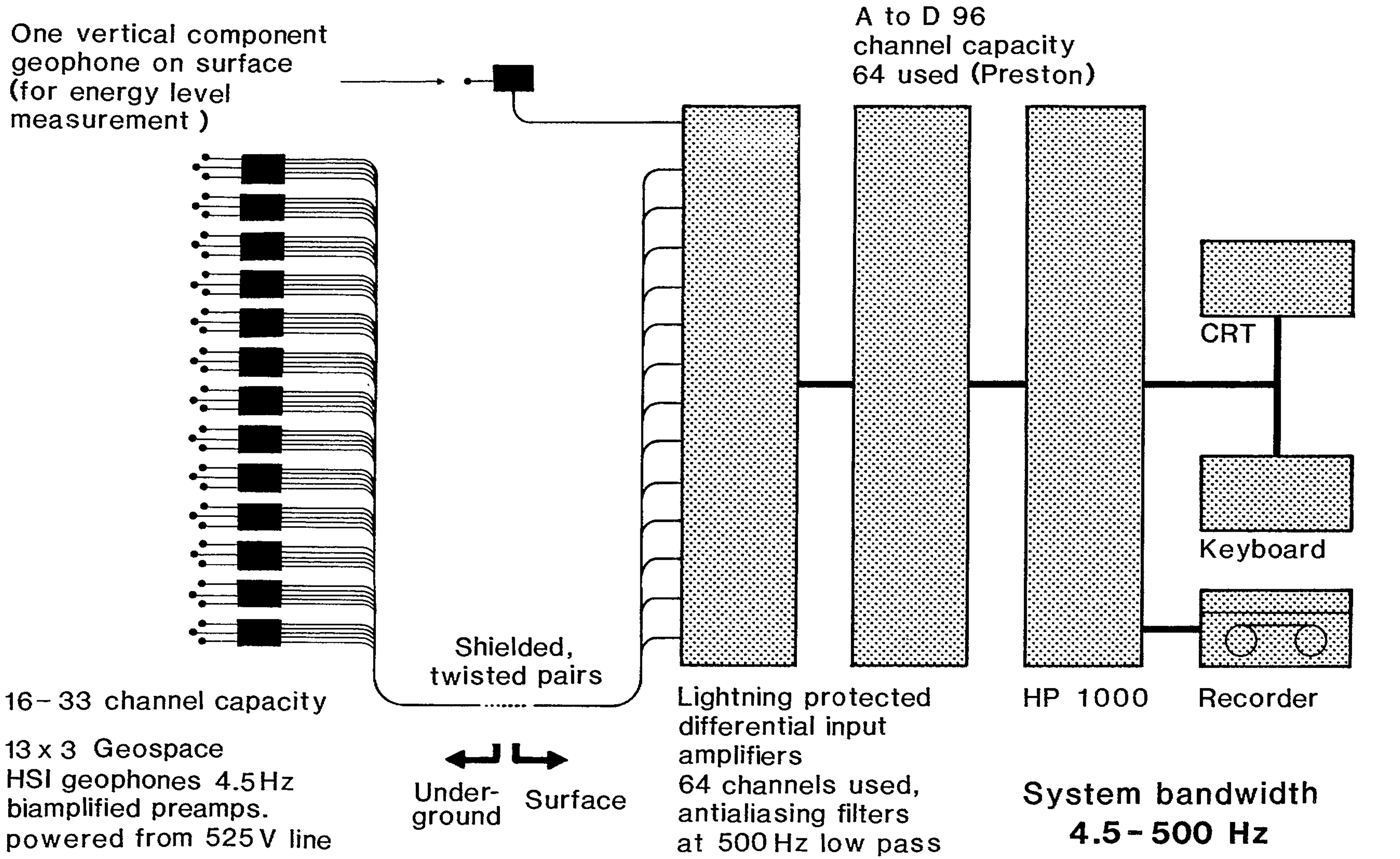
*AMF Geospace,
5803 Glenmont,
P.O. Box 36374,
Houston, Texas 77036 U.S.A.

Figure 4.

MINE WIDE SYSTEM, WESTERN DEEP LEVELS LIMITED

(PETER MOUNTFORT, COMPUTER MANAGER)



It was stated that a magnitude zero event has a corner frequency of roughly 120 Hz and therefore there would be no reason to use an accelerometer for the mine-wide system. Also, accelerometers are generally much more expensive than velocity gauges. It was claimed that accelerometers give a better signal to noise ratio than velocity gauges for signal frequencies above 500 Hz.

The signals are brought to a single Hewlett Packard HP 1000 Computer on surface. The A to D converter has 96-channel capability, sampling at 1 KHz. Waveforms are stored from all channels and arrival times are picked manually. They claim that with the mine-wide system, there is considerable noise or interference and not as good a quality data as with the microseismic system. They are observing considerable resonance in their sensors and are not sure why. Also there are many cases where one sensor in the triaxial geophone goes dead. Again, the reason for this, is not understood.

The data is fed into a hard disk buffer which can store up to 90 triggers or about 1 days's data. Two or three times per day, this is run off to the computer and all events are located. They observe about 30 events per day greater than magnitude zero. The rest of the signals picked up are blasting triggers. The bottom magnitude located or recorded varies over the mine from about -0.8 Richter to 0 Richter.

Mr. Mountfort claims that the macroseismic system does not give accurate enough locations to attempt burst prediction. Even in the centre of the mine-wide system, where they have a concentration of sensors, the best accuracy is only 40 to 50 meters in the horizontal plane. At the edge of the seismic net, one has no idea what the accuracy may be. Locations were observed 300-400 meters away from the reef at the edge of the network. In the centre of the network, the geophone spacing is approximately 1 Km and the location accuracy is plus or minus 40 or 50 meters in the horizontal plane.

A better velocity model may help to increase location accuracy. The present system gives about a ten millisecond uncertainty in arrival pick, which results in a 60 meter miscalculation of location. Cable for the macroseismic system is all foil shielded including the shaft cabling. There are noise problems in the low frequency, especially in the 50 Hz range. Mr. Mountfort noted that some people are using auto-ranging A to D conversion rather than the log amplifier. The Orange Free State Mines and BPI are planning to go to auto-ranging using 12 Bit technology.

3. Visit With Dr. Steve Spottiswoode, At Blyvoooricht Mine - A Division of Rand Mines Limited - Dec. 3, 1985 (Carletonville)

At this operation, a mine-wide system is used (Fig. 5). The mine is some 5 km across; sensors are spaced 700 meters or more apart; cabling used is twisted pair. The system uses 13 single axis Geosource, SM-6B or SM-6/9 B velocity gauges, from Holland*. The natural frequency of the velocity gauges are 4.5 or 14 Hz. The 4.5 Hz type reads up to 500 Hz (approximately). They claim to get 100% recording of events greater than 1.5 Magnitude. The velocity gauges used in the system are all of the vertical type and have a maximum of 4 mm of allowable movement. The sensors have an 11 gram moving mass. Log amplifiers used were designed and built by Dr. R. Green, of BPI. The operating range extends from 10 MicroVolts to 10 Volts. S. Spottiswoode claims that thermal drift in the MicroVolt range has given problems with the log amplifiers and Dr. Green is now building a bi-linear amplifier. Low pass filters at 300 Hz are

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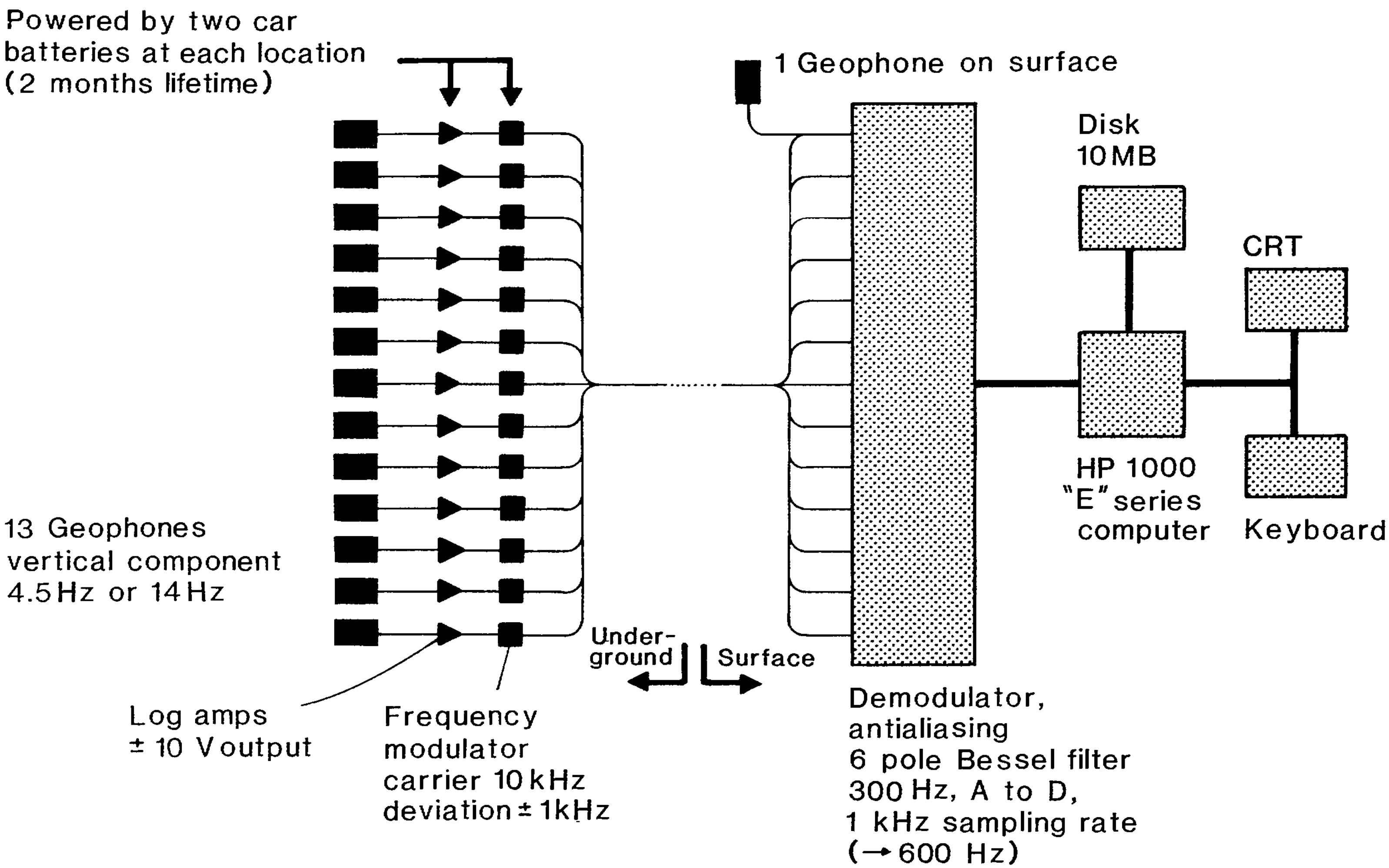
*Geosource - Sensor Netherland,
Rouwkooplaan 8,
2251 AP Voorschoten, Holland

Figure 5. **MINE WIDE SYSTEM, BLYVOORICHT**

(STEVE SPOTTISWOODE)



used. The signals are frequency modulated and transmitted on twisted pair cable. The maximum distance of signal transmission is 12 km. The system puts out approximately 1 Volt RMS, which is picked up at approximately 1/4 Volt at the de-modulator. The carrier frequency is 2.5 KHz, modulation; ±1 KHz.

The log amplifier is located at the borehole collar. The geophones are located in 3 meter deep horizontal boreholes. The geophones are first mounted in a plastic pipe with the geophone perpendicular to the pipe. The system is then levelled up and cemented in.

The in-plane accuracy is claimed to vary from plus or minus 20 meters at the centre of the net to approximately 100 meters at the edge. Dr. Spottiswoode also claims that, at the frequencies recorded by a mine-wide system, one would not want an accelerometer. Additionally, to get displacement, velocity gauges are better than accelerometers since the signals only need to be integrated once. Also, at the frequency ranges that we expect, the velocity gauges should be more sensitive. This is discussed in a paper by R. Green(1).

The preamplifiers are battery powered using two 12 Volt car batteries. These last approximately 2 months and are changed on a rotating schedule. Spottiswoode claims that this results in less mine noise. Some sites are intentionally far removed from mine power in order to minimize induced interference.

The seismic signals pass through a 300 Hz anti-aliasing filter and 12 bit A to D converter. The data is then accessed by a dedicated HP Mini-Computer. The events are picked and written to disk. The event picks are done using amplitude levels and 32 millisecond time windows. The channels are sampled at 1 KHz, there are 32 channels of which one is a coded clock. A second Hewlett Packard Mini-Computer is used to access events. The data can be looked at on the screen and arrival times are then picked manually for P and S Waves. Key data is then written to the header of the seismogram. The first 16 words are used for this purpose. The seismograms are kept in a permanent file. Two 5-megabite disk drives, each holding approximately 100 triggers, are used. Those triggers of interest, are kept on permanent tape.

Spottiswoode noted that a full magnitude overlap is needed with a Governmental Seismic Network. Spottiswoode noted that the waveform was used in order to give confidence in the P and S arrival locations. He noted that due to the early drift, because of the log amplifiers used in their system, they were not able to reliably determine particle motion and also were not able to do Fast Fourier Transforms on the waveform. Most analyses were based simply on location of events. Spottiswoode claimed that we would need a seismologist for approximately 2 years in order to put in automatic P and S wave arrival picking. At the Blyvooricht Mine, events are manually picked first thing in the morning. Secretarial level trained personnel do this, and the work is done in one to two hours presenting no major problems. Spottiswoode noted that in a new system he would recommend that we work to the maximum dynamic range possible.

4. 2nd Meeting With Dr. Steve Spottiswoode - Rand Mines Head Office, Dec. 5th, 1985, Johannesburg.

Initial discussions were on automatic picking of P and S wave arrival times. Spottiswoode noted that he was attempting to use a characteristic function and provided us with a write-up on his algorithm for automatic picking[2]. He further suggested that we review a paper on ARMS in the Rockburst and Seismicity in Mines Conference(3). Additionally, he gave us a paper, titled, "Underground Seismic Networks and Safety", published in August, 1984(4).

Spottiswoode noted that to date, generally constant velocity models are exclusively used in South Africa, except possibly at the Welkom area. Spottiswoode reiterated that the typical accuracy at the centre of a mine-wide network would be roughly 20 meters. This would be where one had, say, five geophone sites within 1,000 meters. Spottiswoode suggested that the conservative rule for designing a system, is to keep the high frequency limit a factor of 4 above the corner frequency. Similarly, the low frequency should be kept a factor of 4 below the lowest frequency. At magnitudes 0 - 2.5, the bandwidth required can be calculated using equation 5 from Spottiswoode's paper(4). The equation is:

$$\text{Log } f = 2.3 - 0.5\, m$$

where f = frequency
and m = magnitude

In that case, maximum frequency is approximately 800 Hertz and minimum frequency is approximately 5 Hz. On the question of what would constitute an ideal sensor, Spottiswoode noted that, at present, we are dealing with farfield body waves. Additionally, it would be good to look at nearfield waves. This would require a strong motion instrument. He also suggested that it would be good to look at other phenomena, especially electro-magnetic waves. In quartzite, one would expect electro-magnetic waves to be generated. One would also expect very strong attenuation at frequencies >1 MHz. He noted that the electro-magnetic energy might be due to piezoelectric effects or twinning in quartz crystals.

On the problem of selecting triggers, Spottiswoode noted that he tried to look for coincidence at any instant in time. Then, if any two out of five sensors stayed high, one can assume that this is a proper trigger. Spottiswoode stated that he believes that most improvement in rockburst analysis can come from better analysis of data, not necessarily better instrumentation.

5. Meeting With Dr. R. Green - Bernard Price Institute For Geophysical Research, Dec. 5, 1985 - Johannesburg

The Goldfields mine-wide microseismic system was designed and built by Rod Green. The system utilizes logarithmic data compression underground (log amplifiers), giving a dynamic range of about 100 decibels. After logarithmic conversion, the signals are sent through a frequency modulated transmission system to get around the typical 50 Hz line noise problem. At surface, the signal is demodulated and digitized by a 16 Bit A to D converter. Radio telemetry is used to transmit signals from various mines for central processing at the West Driefontein Mine. Six mines are covered by the macro network. Seismic events located at the remote locations are transmitted by radio telemetry back to the mine sites. Complete seismogram data are collected.

Triggering is done utilizing a hardware trigger. The trigger relies upon the aperture of the microseismic array (i.e. the time between triggers at various geophones) and the duration of the signal. Four trigger units must be hit before it will be classified as an event. The system has a few triaxial sensors, however, most sensors are single component velocity gauges. Green noted that in future they may wish to look at a small network (i.e. a microseismic network as at Western Deep Levels) in combination with the macro network. In such a case, they will have to look at different aperture and duration criteria for triggering. All of this can be software controlled.

Initially, 16-Bit micro-processors were placed at each head frame. These processors were intended to look after the 32-channels from that particular shaft. The 16-Bit machine then transmit this data to a 32-Bit machine at the central processing laboratory at West Driefontein. A large number of problems were encountered with the 16-Bit micro-procesors; specifically, the inability of the software to cope with the volumes of data encountered. Green believes that they could have done better with hardware. He notes that industry only wants location and energy and this could have been supplied using hardware. All of the rest is really for research.

Green has carried on with the development of a digital system, on which he is working with students from the University of Witwatersrand. The underground system now under development, will be for 8-channels and will include gain ranging. Green noted that seismic data does not need 16-Bit precision, rather it requires a large dynamic range with about 1% precision for amplitude. The system presently in development, uses 30 Decibel gain steps with 8-Bit conversion along with 2-Bits for gain information. He plans to run it with a 68,000 micro-processor and fibre-optic data link. He further intends to use high speed data transmission at mega-byte rates. He is setting up at first to use the new system in parallel with an existing network.

Green intends to hook the signals into a PC XT micro-computer. He claims to have the complete software developed for data acquisition. The system in its present state can be used as a precision digital data aquisition line. The next step is to hook into the IBM PC at mine sites at Carletonville and do processing right at the mine.

Green claims that BPI have done considerable development on software for the new system. Developments to date include automatic picking of P and S wave arrival times and Fast Fourier Transforms. In future, they will be adding determination of seismic moment, stress drop, etc.

Concerning the log amplifier, designed and developed by Rod Green, he noted that this technology requires a great deal of precision set-up and that it is really a research tool. Green claims that part of the problem encountered by Spottiswoode is that the system was run off batteries. He claims that the batteries were allowed to run down too much and this caused thermal strains which damaged the system. Green noted that existing log amplifiers are not suitable because the band-width is too small. Green is presently developing accelerometers and geophones sized to fit in boreholes. He is also working on a 1 Hz geophone that will have a 1 kg moving mass.

6. Visit To Chamber of Mines Research Laboratories - Dec. 6th, 1985, Johannesburg

6.1 Meeting With Dr. Nick Gay

Dr. Gay noted that a large network covering some 500 sq. km was run by the geological survey; this covered many mines. Additionally, large mining houses such as Anglo-American, Gencor, and Rand Mines run regional networks. The national network uses 1 - 4 Hz Geotech Teledyne sensors. The regional networks use 4.5 - 14 Hz velocity gauges. The Klerksdorp area is covered by a Chamber of Mines network. The Carletonville area has its own network and East Rand Propriatory Mines (ERPM) is also putting in a network at present. Additional to these mine-wide or regional networks, they are also looking at close-in networks of roughly 400 - 500 meters. In these close-in networks, they would look at placing 16 to 20 triaxial geophones located in a three dimensional array. They are interested at looking at what causes the triggering of seismic events in geologically complex areas. They are presently installing one such system at Vaal Reef Mines. They are looking at an area of complicated dyke and fault geology, which they expect to be active. The original system was a counting system only. The systems are discussed in a paper by Johann Scheppers, in the Seismicity in Mines Bulletin[5]. Based on these original counting type systems, they have decided to go ahead with a more sophisticated system which is now being installed. They plan to install one such microseismic system at Goldfields West Driefontein Mine. This will be a 400-500 meter secondary network, which will be installed to look at a triangular remnant which is going to be mined out. The planned system will operate within the West Driefontein mine-wide system and is planned to look at the effects of geological structure and backfill.

6.2 Discussions with Ken Patrick, Electrical Engineer

Ken is apparently one of the Chief System Designers for the Chamber. Ken noted that the Chamber uses model Sensor SM-6B velocity gauges. The geophones are installed in a steel rod. Three holes, mutually perpendicular, are drilled in the rod and the geophones are epoxied into these holes(Fig. 6). The complete assembly is then epoxied into a BX-sized borehole (Figures 7,8). He noted that resonance had been a problem with the triaxial sensors. They had done some shake table tests and encountered problems in the low frequency end at high displacements, but did not find a cure for the triaxial resonance problem. Simple mercury switch arrangement can be used to position the triaxial gauge.

Accelerometer systems are used for microseismic studies, such as at Western Deep Levels. Accelerometers are also useful if one wishes to look at peak velocity since they have a higher dynamic

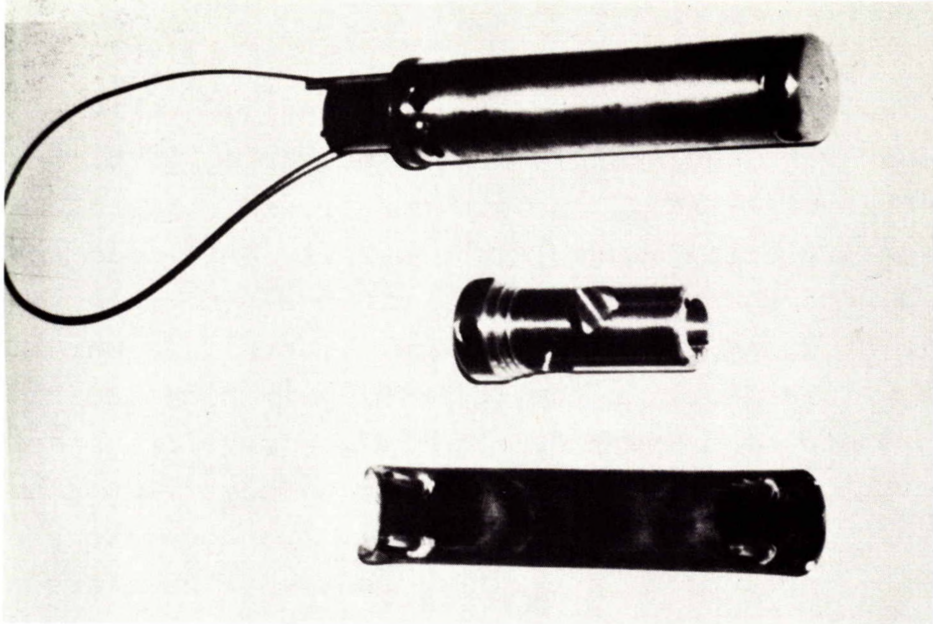


Figure 6. Triaxial geophone assembly used by the Chamber of Mines.

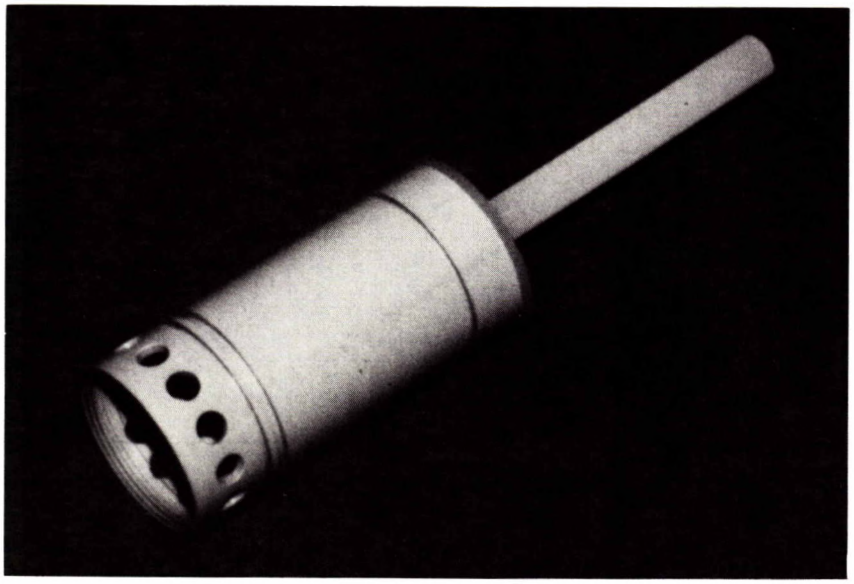


Figure 7. Plastic syringe delivers epoxy resin for mounting geophone assemblies.

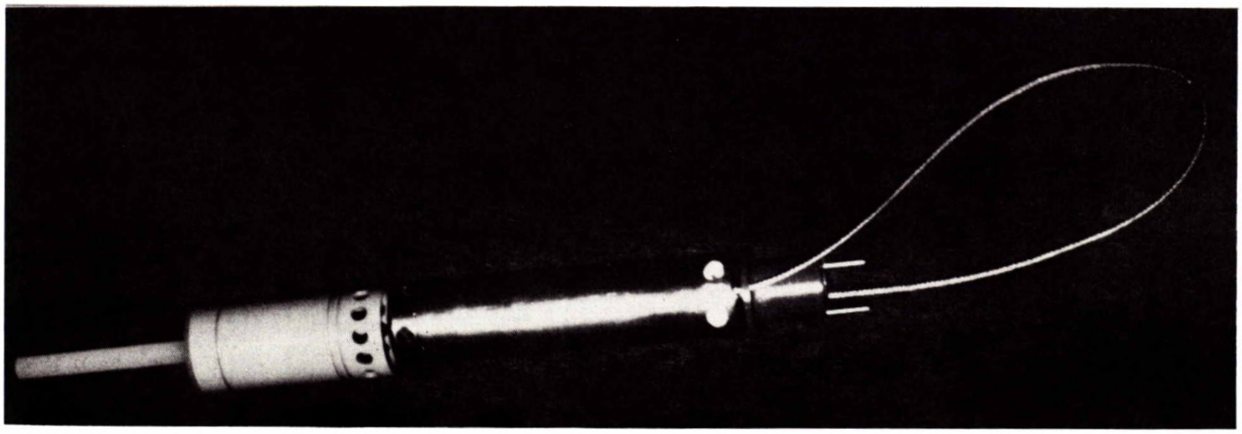


Figure 8. Plastic syringe and triaxial geophone assembly prepared for installation.

range. The signals can be integrated to give the velocities. The Chamber were successful once in measuring particle velocities between 0.2 and 1.1 meters per second, some 50 meters from the source. Velocity gauges are generally only good up to about 0.9 meters per second maximum. Peak particle velocity is of use in studying rockburst damage. There is a paper on this topic, by Art McGarr, in the Seismicity in Mines Book[6]. Accelerometers used are Model BBN-507. These are based on piezoelectric sensors and cost approximately 2,000 Rands. The Chamber are considering building their own accelerometers, with a frequency range of 2 Hz - 2 KHz, however, there are problems with calibration of these units.

6.3 Meeting with Johanne Churcher

Johanne is in charge of programming for the Chamber's seismicity efforts. With their systems in place, the Chamber receives a daily tape of events which is then processed overnight. The data stored on disk include source locations and the complete seismogram. The underground system has automatic P wave picking and could also do source location underground. She is presently working on a new P wave picking algorithm. For the microseismic systems, they need a very fast algorithm since they expect somewhere around 1,000 events per day. Larger regional systems have more time (i.e., record fewer events), and therefore can use more complex source location algorithms. The current algorithm calculates a noise level and from this it sets a threshold; then it takes approximately 1-1/2 times the noise level plus an offset. It searches for a sample which exceeds this threshold and it calls that the arrival time. The algorithm however, is susceptible to spikes. In the case of larger events, arrival times will be repicked by hand. With the present system, they tend to see consistent errors in P wave arrival time picking. Arrival times tend to be consistently picked early. Where uniaxial stations are used, it is sometimes difficult to differentiate between P wave and S wave arrivals. The software is being developed around the basic Chamber of Mines' data base. As noted, processing is done overnight and the basic data is being stored on disk. Analyses performed include magnitude of the events; locations are plotted on mine plans plus the geology and they have the key geology on coloured graphics. Energy is calculated and magnitude frequency relations for the full seismogram are recorded. From the seismogram, spectral Fast Fourier Transforms are used to derive corner frequency, stress drop and seismic moment. First motion analyses are also conducted. In the arrival time picking algorithm, they plan to compare arrivals and use an outlie detection system. Any outlies will be rejected. The basic algorithm was derived by Salamon and Wiebols(7). This requires less than 1 second to do a location; with outlie detection, this may take 1 minute. There is a comparison of algorithms for source location in a paper in the Seismicity in Mines Book(8). Programming is all done in Hewlett Packard Basic. They use an HP-9920 which is a 32-Bit machine and it has 3/4 of a Megabyte Ram. A 65 Megabyte Disk is also included.

6.4 Meeting With Dr. Nigel Legge

The Chamber is using microseismic networks to monitor the formation of fracturing ahead of the face. They are interested in looking at events of magnitudes between -2 and -5 Richter. This is effectively an acoustic emission type of measurement. They wish to know how far ahead of the face fracturing begins to develop and what orientation it may take. Source location accuracy is a problem in this area. Automatic arrival picking is necessary and they intend to discard the waveform after source location. Hardware is quite similar to that discussed previously in Sec. 2.1, but the software is different. Only arrival time and energy are recorded for the events. Waveforms could be recorded if required. It is planned to record one waveform per day for calibration. Model BBN-507HS accelerometers are used in the uniaxial mode. They plan to cast the sensor in a resin boat. This resin boat will then be set behind a syringe full of sulphite and inserted in the hole. The syringe can then be pulled back and the boat driven into the sulphite. This is allowed to set, then the installation rods are unscrewed and removed. These units can be installed in 35 meter holes.

They are not intending to use FM modulation, rather they will transmit the baseband a short distance to the processor. System bandwidth is 10 KHz and the signal will be sampled at 30 KHz. They originally expected about 1,000 events per day and found that the number of events actually varied between 200 and 2,000 per day. Arrival times are picked underground. The signal is integrated to obtain velocity. Sum of squares is used to derive energy. This is recorded on digital tape and taken to surface for source location. The captured waveforms are also recorded digitally on tape. With the accelerometers used, the low end of the frequency spectrum falls off rapidly below about 200 Hz, therefore, the units are not good for displacement studies. An envelope method was used for triggering purposes. They were able to locate roughly 65% of all the events and 75% of events which were picked up by more than 4 geophones.

Dr. Legge is a Rock Mechanics Engineer, and is interested in investigating rock fracture. He is looking into the formation of stable mine induced fracturing ahead of the working face. South African gold mining is very labour intensive. They wish to get information on the mechanism of fracture formation and use this to design stopes to minimize hazards to personnel. Microseismics is being used as a tool in this effort. They noted that they see two basic types of rockbursts; a burst occurring due to movement on pre-existing structures such as faults or dykes and bursts associated with unstable fracturing around advancing stope faces. They recommended that sensors be positioned in relatively unstressed ground. For microseismics, one should expect corner frequencies of about 2 KHz, which relates to a source dimension of a few centimeters. It is suspected that the events recorded are from a number of individual events and that these eventually coalesce to form major fractures and hence large magnitude bursts.

6.5 Future Developments at The Chamber of Mines

The Chamber of Mines is interested in developing a portable seismic network. The present ones being used in South Africa are not portable and require one to two years to install, must cover several levels, are bulky and expensive. The existing mine-wide systems are useful to determine areas of concern. They would now like to develop a portable system to go in and look at these "hot spots" in more detail. The question is whether to build or buy. We informed them concerning developments at Instantel in Canada, however, it is doubtful that Instantel would be ready in time for their needs.

They noted that the planned system in question had certain peculiarities. First the Mines want a transparent system that simply gives location and event energy. The Chamber, however, want to get more out of this data.

7. Meeting With Anglo American Corporation at Welkom, Dec. 9, 1985

7.1 Meeting With B. Davies and M. Dix

Mr. Dave Ortlepp of Anglo American Corporation introduced the two section heads for rock mechanics services; Mr. Bernie Davies and Mr. Maurice Dix. The groups are divided into Rock Mechanics Services and Rock Mechanics Projects at Welkom. Rock Mechanics Services have approximately 19 employees and approximately 14 projects. Rock Mechanics Services people are assigned to each production manager. Anglo-American have approximately 8 gold mines in the Welkom area some of which are now in the process of being rationalized into one giant mine. For standard administration purposes, this has been divided into two sections - north and south, handled by the two section heads respectively. This new giant mine is called the Orange Free State Consolidated Gold Mines Limited, which employs some 70,000 men underground; about 50,000 of these are black workers.

The original mines which are lumped into the new super mine produced in the neighborhood of 200,000 to 250,000 tonnes per month. Now, the new shafts being put down are planned at 250,000 tonnes per month. We were given a paper by R.L. de G. Solms on the construction of new shafts[9]. The mines are now looking at mining material with grades as low as 4 grams per ton, therefore very high tonnages are needed if these are to be made economical.

7.2 Dramatic Seismic Events in the Welkom Area

In December 1976, a seismic event, since known as the Welkom Earthquake, occurred. The event exceeded magnitude 5 Richter and resulted, some two hours later, in the collapse of a six-story apartment building. They were able to evacuate all people from the building prior to its collapse. Apparently this structure had been very poorly constructed since other structures of same size and type, around it, were not disturbed by the event. Underground, 23 cm displacement was observed along the fault structure.

In April, 1982, an event occurred on one of the north-south strike faults. The movement damaged both the No. 4 and No. 1 shafts which were subsequently out of commission for two days. As it occurred, the No. 4 and No. 1 shafts acted as emergency escape-ways for the other shaft respectively. This resulted in some 10,000 men being trapped underground. These had to be taken out through old escape-ways. Only two fatalities resulted from the event, which was magnitude 4.2 Richter. Fault displacements of up to 40 cm were observed underground.

The geology in the Welkom area is cross-cut by a series of normal, roughly north-south, strike faults. These faults, plus other cross-cutting structures, result in the mining faces being broken into relatively short pieces. This makes conventional longwall mining at depth impractical. Often in these areas they have to predevelop. This results in often having to leave pillars over development workings. Major problems may result due to the high stress areas below the pillars. Additionally it leads to mining certain amounts of waste. In some areas they have to go to very scattered mining, leaving a large number of remnant pillars. The stope widths are nominally 1 to 1.5 meters. In lower areas the stope widths are up to 2.5 meters. A second reef occurs some 20 meters above the main present mining area. This reef is some 2 meters thick. It is considerably lower grade but since the development headings are already in place it is probably economic. The cut off on this reef is assumed at 3 grams per ton. There is evidently, in this mining area, a need to understand fault slip movements to predict future movements. The early seismic system first installed in the Welkom area was strictly an event location system and appears to have been very similar to the present Electrolab system from the U.S [10]. They are now upgrading the system. The original system, while not retaining the complete seismogram and hence having problems in determining what the actual arrival times were, still was able to delineate areas of abnormal seismic activity. The rock mechanics section heads noted that we should be careful not to just look at locations in two dimensions. As locations in vertical sections were also very important. They also noted that damage location can be very deceiving in terms of source location. Source locations in the Welkom area indicate that they have a bias towards activity in the footwall. They do not believe that the locations can be far enough off that the above indication would not have considerable meaning. At western deep levels on the other hand, most activity occurs around the stoping areas. In the Klerksdrop area, activity is primarily along key geological features. Hence there seems to be different seismic mechanisms in different mining areas.

7.3 Meeting With Alexander Mendecki, Seismologist, Welkom, Orange Free State, Anglo American Corporation

Mr. Mendecki emphasized that in rock burst seismology, a good seismic geophone array is needed to obtain locations and real ground motion. If insufficient stations were included in a large area then it may be difficult to get adequate location accuracy. He further noted that any seismic array has its own "blind spot". The criterion for determining such a blind spot depends on the seismic array and seismic velocities. Mendecki noted that one had to be particularly careful about the Z coordinates, coordinates in the vertical plane. He noted that for a given site one begins by specifying the number of geophones. Eleven triaxial geophones are needed to locate events at better than 1% accuracy. He noted that there is an optimum number of stations, i.e., sometimes fewer than eleven triaxial geophones may be better. He suggested that if the velocity structure of the ground is known, seven or eight geophones may be sufficient. If not, then one needs at least eleven. He then noted that calibration of the array is extremely important. He suggested that one first calibrates the array, then calculates the optimum velocity structure plus the error. One then reiterates using different events to optimize this. He may have implied a seismic tomography type of analysis, although he did not use this term.

Mendecki noted that it is easier to get true ground motion with velocity gauges as compared to accelerometers. Velocity gauges also have a better signal to noise ratio. Mendecki continued to stress the importance of obtaining so-called real ground motion. He said that if our interest was between magnitude 0 to 2.5, then we should look at a frequency range of 4.5 hertz to several hundred hertz. He suggested that mine damage occurred in the 1 Hz to 100 Hz range. Therefore, we should look at a 200 to 300 hertz upper frequency limit.

Dave Ortlepp suggested that we should take our system beyond the 2.5 magnitude limit and suggested a 3.5 magnitude upper limit. Mendecki suggested that we scale events to seismic moment not to magnitude. Mendecki noted that in order to extend our system beyond magnitude 4 we would have to drop the low frequency end below 4.5 Hz. The suggestion was, in this case, to put in a single 1 Hz unit. The velocity of particle motion is given by the equation:

$$V = \log \frac{A}{T} + Q$$

He noted that the seismic moment is given by the amplitude at very low frequency. To be sure to have the flat portion of the frequency spectrum, therefore, one must drop the frequency limit. Mendecki suggested that Geospace sensors are adequate. They have had almost no failures of geophones. He suggested that we check the geophones on a shaker table when we first get them to do our own calibration. He also suggested that we keep the geophones as far away from the seismic source as possible. The suggestion was again made that we include at least one, 1 Hz seismometer as a surface unit in our program. This would allow us to tie into the national network, in terms of magnitude.

7.4 Meeting With Rob Dixon, Anglo American Corporation Welkom Orange Free State

Mr. Dixon is apparently the key man in electronics at this location. The new system presently employed uses 31 triaxial geophones. The three velocity gauges are epoxied in a brass carrier which is then epoxied into an eight meter borehole (Figures 9, 10). Signals from the geophones are bi-amplified by 1x and by 1000x. The signals are digitized at the borehole collar; software is then used to select which signal is optimum. 12 bit, A to D conversion is used and is microprocessor driven. Four buffers, each 24 kilobites long, are then used in a circular fashion until a trigger is seen. This allows four seconds of data to be saved for each geophone. A time signal is sent each five minutes to synchronize the system. Five additional stations are planned, fairly close to the mining zone, to obtain as accurate source location as possible. Due to the mining geometries the system as set out covers both Anglo American and Gencor Properties, although the system is run strictly by Anglo American. Typical uncertainty in locations varies from 20 meters to 100 meters. However, they do not believe that the present algorithm is as good as it might be since it was designed some six years ago. They are planning to improve this in future. The key factor with the system is that data is digitized underground at the borehole collar. Digital data is then transmitted on simple twisted pair telephone cable to the surface and then radio transmsitted to a central processing unit from each shaft.

Details of the system were then given by Mr. Paul Armstrong and

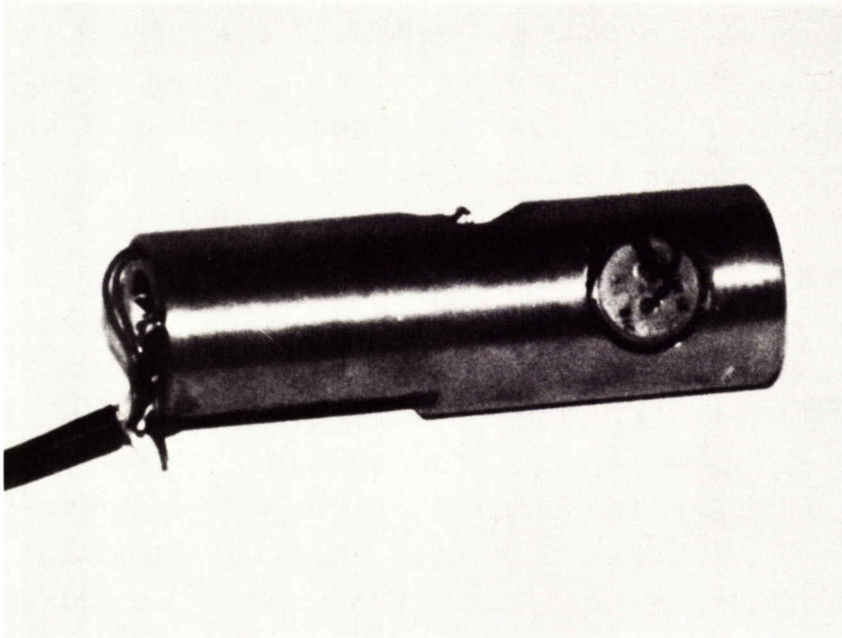


Figure 9. Triaxial geophone assembly used by Anglo American Corporation. Sensors epoxied onto machined brass rod.

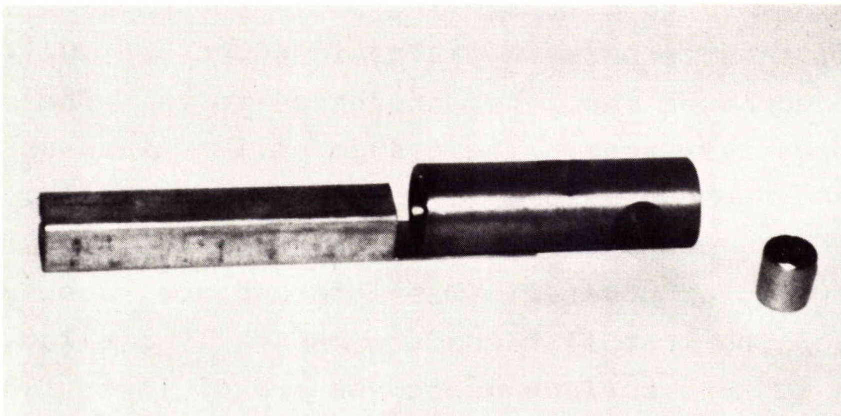


Figure 10. Components used for triaxial geophone installation; square allignment tool, machined brass rod to hold geophones, and geophone. (One of the three used shown.)

Mr. Bernard Diab. A surface field site was then visited (Fig. 11). We were told that other than the method of supplying power, which at the surface field site was solar, the set up was exactly the same as the underground site. The surface site included an analog signal processor, a processing rack, a 6800 chip CPU and A to D conversion boards, a power supply and a radio transceiver (Fig. 12). The geophone itself was set in a 2 cubic meter concrete block near ground surface.

8. Meeting in Klerksdorp Area, December 10, 1985 - Stilfontein Mine To Review Chamber of Mines Run Mine-Wide Network

The key person from the Chamber of Mines on the network was Mr. Johann Scheepers. The Stilfontein Mine is owned and operated by Gencor* of South Africa. The group rock mechanics engineer is Mr. Roger More O'Ferrall. Most of the system description was given by Mr. Scheepers. In the Klerksdorp area, larger events run between magnitude 3 - 4 Richter. Events are generally structurally controlled and occur along faults or dykes. Macro-seismic monitoring started in 1976 and consisted of five tri-axial geophones. Output from the triaxial geophones was rectified and summed to make sensing omni-directional. In 1976 a full time technician was assigned to the system and the number of geophones was later increased to 28. The monitored area was also increased. The system as it exists at present consists of 28 geophones; 10 or 11 of these are shallow, the rest are intermediate to deep. Six geophones are located on surface, five of these are solar powered. The intermediate, deep and surface geophone installations are basically similar. The only difference is that surface geophones are of lower frequency, being 4.5 Hz velocity gauges. The Chamber would recommend that these gauges also be used underground. In the Klerksdorp system, however, underground velocity gauges are HS-J 14 Hz geophones. They also have some 2 Hz geophones for surface installation.

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*General Mining Union Corp. Ltd.

Figure 11. Surface field site for microseismic network. Data transmitted by radio. The complex electronic equipment is powered by solar electricity. (Anglo American Corporation)

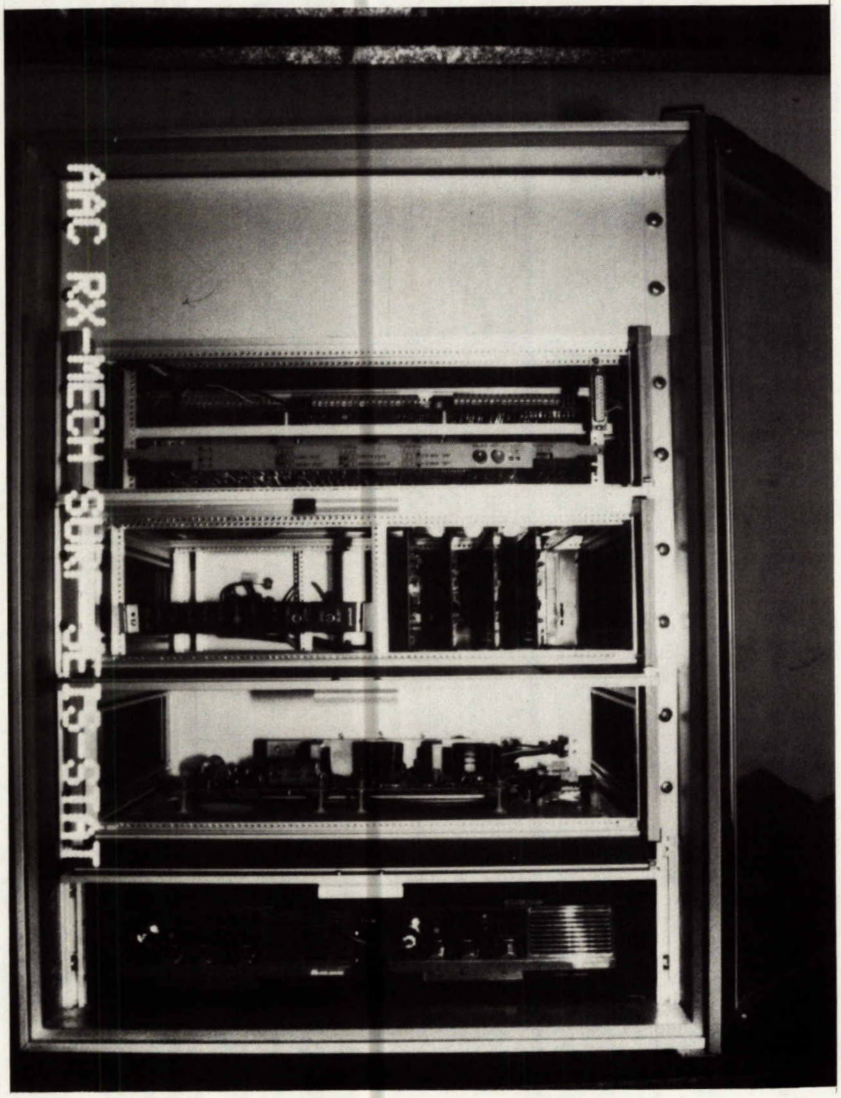

Figure 12. Microseismic hardware; analog signal processor, A to D converter, microprocessor, radio transmitter and power supply.

In the present system all of the geophones are triaxial, however, due to processing limitations, they are only monitoring one component of the triaxial geophones. Signals are sent up to surface in frequency modulated form using three carrier frequencies. The carrier frequencies are 1875 Hz, 3125 Hz and 4000 Hz. The signals are superimposed and sent to a UHF transmitter. This transmitter cannot handle signals much above 4000 Hz.

An area of some 300 square kilometers is covered by the macroseismic system. In the Klerksdorp area system, geophones are located mainly in the shaft pillar for reasons of maintenance and protection. They have found that if geophones are located too remotely, power cuts, etc., occur and it is very hard to get back and reinstitute the geophone. Generally, in the existing system most geophones are operational most of the time. Signals are transmitted from underground through cables in the shaft to a UHF transmitter. The receiver for the UHF signals is located at the Marguerite shaft. Some geophones were placed in 30 meter holes in the back and the floor in order to achieve some three dimensional coverage. Source location accuracy in the macro system is 60-100 m.

They have done some calibration shots and found approximately 2.5 meter accuracy in the XY, or horizontal, plane and about 5 meter accuracy in the vertical plane in the macro network. During their calibration shots, they have been able to determine a velocity difference in front of and behind the working face. The velocity appears to vary from about 3 kilometers per second to roughly 6 kilometers per second. Their studies indicate that structured and fractured ground can have a strong effect on signal performance.

The Chamber has found that lightning causes problems in UHF transmission that can lead to continuous triggering. They use a multichannel tape recorder as a backup and hope to be able to drop this in the next couple of years. The Chamber intend to recalibrate their whole system again soon. They recommend that calibration shots be run quite often. Large events tend to saturate the amplifiers. They suggest that one might get around this problem by using bi-amplification with a large gain difference between channels.

The Chamber have not observed any systematic change in errors of particular geophones with time that would suggest a time dependent change in velocity, i.e. they have not observed anything that would suggest a change in the fundamental nature of the rock mass with time.

The Chamber noted that the system in use has two purposes; the first is for management reasons and the second is for research purposes. They noted that management are interested in locating dangerous structures and the amount of seismic energy released. The Klerksdorp area tends to get more large magnitude events than do other areas. The lower limit of the system is about 0.5 magnitude Richter. The Chamber noted that they can detect signals less than magnitude 1 but they have to guess at the magnitude of such signals.

The system (Fig. 13) has an event simulator which can be used to test new software. This allows the Chamber to debug new software without waiting for actual events. The event simulator puts in a delayed time and a decaying sine wave for any selected 10 channels. The chamber has a chart paper recording of seismograms. However due to cost of the thermal chart paper, they are finding this an expensive system to run. If a large event occurs, the first two or three signals are readable, after that it is very hard to distinguish anything out of the 20 overlapping channels on the chart recorder.

A surface seismogram unit is used to correlate with the National seismic network. This unit gives a 24-hour chart record. The geophone, which is a vertical 1-Hz single-axis unit, is located

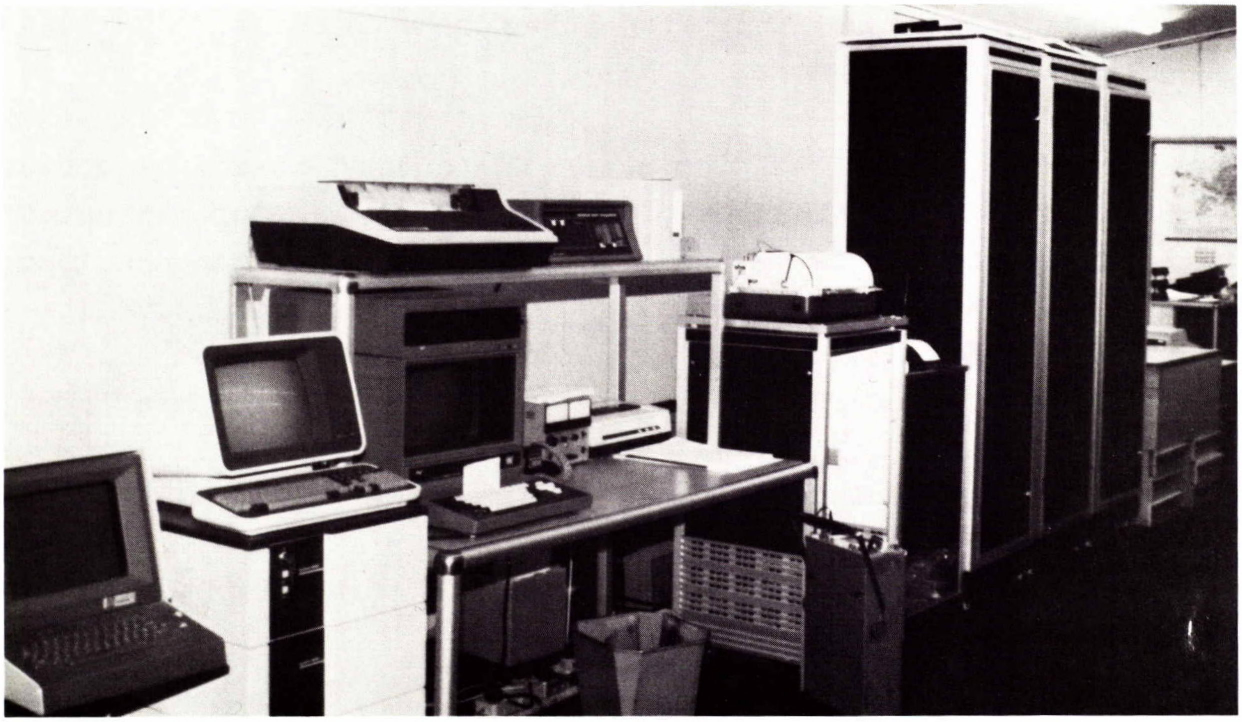

Figure 13. Macroseismic system of the Chamber of Mines located at Stillfontein Mine, Klerksdorp area.

some fifteen meters into bedrock and is buried in two cubic meters of concrete in the bottom of a 22 meter hole. The range of the unit is from .2 to 5 Hz.

The larger events of the Klerksdorp area, ranging from magnitude 4 to 5, are plainly felt on surface. Serious surface damage to structures also occur; some structures have to be destroyed and rebuilt.

Dow Corning conformal coating material was used on all electrical circuit boards that are sent underground. It was further noted that the Chamber tends to use a fair bit of intelligence at the undergound stations. A typical new shaft site underground station includes an analog to digital converter, a trigger board, a RAM board, a CPU board, a communications board and a power supply. These are located in 10" x 4" boxes which are placed in large stainless steel sealed cabinets. The cost is roughly 4,000$ per channel at the sensor end. Surface stations at the Klerksdorp area are the same as surface stations used at Welkom.

The Vaal Reefs Mine owned by Anglo American sits within the Klerksdorp macro network. Vaal Reefs uses a microseismic network on a 400 square meter area. This micro net consists of 16 triaxial geophones to do source location. The idea is to locate micro events. No seismograms are recorded. The system uses HS-J geophones, which operate from 14 Hz to a few hundred Hz. Throughput time on the system is roughly 3 seconds; thus an event can be located each three seconds. In the past two years, some 144,000 events have been located. 85% of these were due to blasting. Micro event magnitudes range from -0.2 to about 0 Richter.

The Chamber are planning a new network in a different part of the mining area. The new network will include 13 new geophone stations. Seven of these will be underground, six on surface. They plan some increase in the density of geophones in particular areas of high seismicity. The new network is planned to have better vertical coverage. This, naturally, will result in additional maintenance problems.

The area to be covered will have seven channels on the sixty-sixth level, nine on the sixty-eighth and one some 40 meters above the sixty-sixth level in the centre of the net. The geophones will be installed in six meter deep holes. The Chamber suggested that the depth of hole required should be sufficient to get beyond the superficial fracture zone. The deeper the geophones are placed, the less surface noise occurs. The rule is a placement depth of two times the tunnel diameter. The new network will use triaxial geophones. Locations will be done underground. The micro-processor underground will be used to control analog to digital conversion, etc. and then to communicate to a master processor underground. The location algorithms by Wiebols and Salamon will be used. This algorithm gives XY & Z deviation. The determination to be used is that if the average deviation exceeds 20 meters, the event will be discarded. For those events which are kept seismograms will then be sent to the surface where more accurate checks of P and S arrival times will be done.

With the new system, when collection of full seismograms is ongoing, there will be roughly a 20 second period when the seismograms are being transmitted. Strictly speaking, in that period, they cannot collect or locate events. In order to accommodate this, each triaxial geophone has a small built-in CPU. The CPU can store a few events while the main processor is transmitting data. Additionally, during blasting they will source locate only and will not try to maintain any full seismograms. Additionally, they are considering maintaining seismograms only from events greater than a particular size or possibly based on the duration of events.

The proposed new system will use the same hardware event picking techniques as the old system discussed previously. The system was designed to do a preliminary source location underground. If the source location is deemed adequate (i.e. not too far off the standard deviation), then the system will ask for full seismograms from outlying stations. These seismograms will be used to hand pick P and S arrivals, if time permits, on surface. The Chamber noted that they will probably try to use an autopicking technique. This will probably be based on energy.

9. Meeting At The West Driefontein Mine of the Goldfields Group, South Africa.

Meeting with Mr. Kevin Reimer, Mr. Martyn Jones and Mr. Wickus Saayman.

At West Driefontein, the carbon leader and the VCR Reef zones are mined. The network here is newer than most other networks. When mining in VCR, mangitude 2 - 4 rockbursts occur. They need to know where these events are located for purposes of rescue, mine planning, etc. The seismic network was originally just for the West Driefontein Mine. It was then decided to extend the network for the complete Goldfields Group in this area. They decided on a centralized system which was to cover eight mines. The objectives of the system are as follows:

a) To provide a fast source location facility.
b) For mine planning, if a cluster of events are observed in particular locations, then management can be informed and appropriate action taken.
c) For long-term detailed research on frequency, magnitudes, etc., of the events.

The area coverage of their system is very large, some 26 kilometers from end to end and includes some 8 mines. The system includes 4 remote sites, one at the Koof Mine, one at West Driefontein and the Doornfontein Mines. One additional mine is planned for next year. Originally there were only four people to run the system. They are presently up to six but still are understaffed for the size of the system being used.

Single axis 4.5 Hz vertical Sensor velocity gauge geophones are being used. They do have a few triaxial sites, roughly one per mine. These are used to determine magnitude of events and to perform seismic moment calculations, etc. Geophones are placed in three meter deep holes to get away from the near surface fracture zones. The geophones are currently epoxied into the back of the holes. No special precautions are taken. Amplifiers are placed at the borehole collar. The maximum distance between the geophone and amplifier is 100 meters, however, most are within 10 meters. The system was designed by Rod Green of BPI and log amplifiers are used. The technicians at West Driefontein consider the log amplifier to be the heart of the system as it gives a very wide dynamic range from negative Richter values to +4 magnitude.

Radio transmission is used between remote sites and the central processing system (Fig. 14). Using the remote sites they are able to use locations from various mines and locate events outside of the array more accurately. The remote sites have a 16 bit microprocessor. This processor logs the signals, stores this on a disk, transmits it as soon as possible, using UHF to the central processing unit. Radios use 40 Kilobaud processing. Additionally each remote site has a 10 megabite disk. Five megabites are hard disk and five removable. They are having problems however since they find that when they are transmitting locations this interferes with data monitoring on the 16 bit computers. The central processing unit uses a 32 bit computer. Each 16 bit microprocessor at the remote sites have two A to D boards and log 24 hours per day. Sampling is done at approximately 1 KHz and 32 channels can be accepted. At

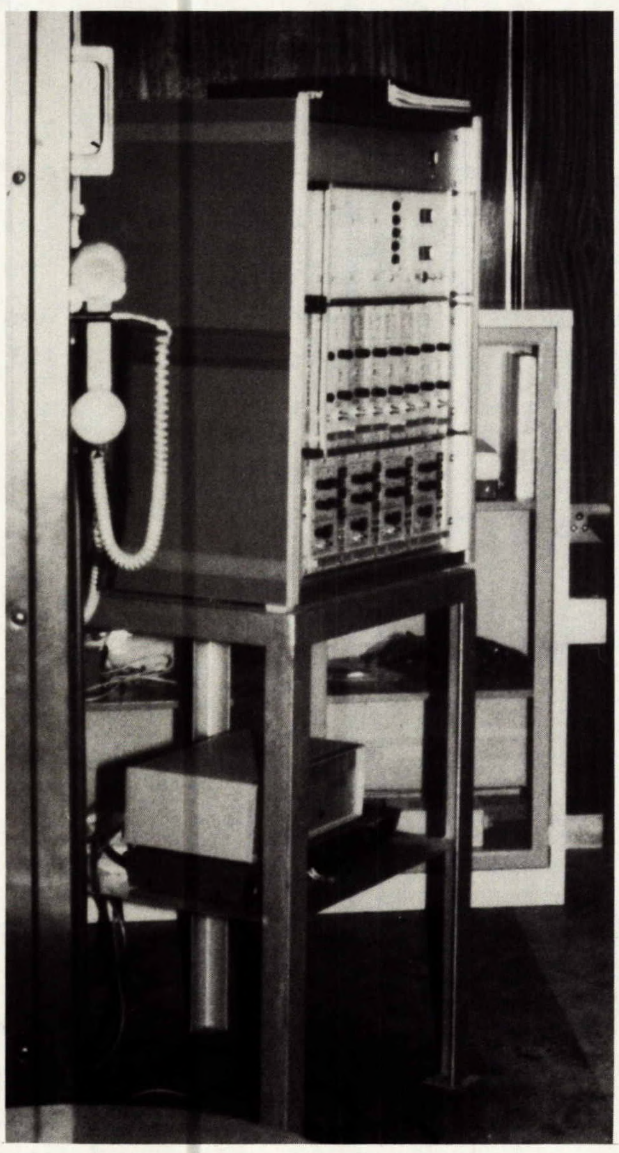

Figure 14. Radio telemetry station, part of the seismic network at the West Driefontein Mine.

present, West Driefontein has 26 channels, Koof has 16 and Doornfontein has 12. Over the east and west Driefontein mines there is some 1000 meter spread vertically over the array.

A hardware triggering system is used. Each trigger is assigned four geophones. Ideally, these four geophones are the first to see an event.

References

1. Green, R.W.E., Design Considerations for an Underground Seismic Network - Proceedings of the 1st International Congress on Rockbursts and Seismicity in Mines. Johannesburg, 1982. SAIMM. Johannesburg 1984.

2. Spottiswoode, S.M., Automatic Selection of P and S Wave Arrivals. Schematic Version of Algorithm in Use at Blyvooricht Gold Mine. Collected in person by W. Bawden (Noranda Research Centre) during South African visit, Dec. 1985.

3. Hanks, T.C., Arms and Seismic source Studies. Proceedings of the 1st International Congress on Rockbursts and Seismicity in Mines. Johannesburg, 1982. SAIMM. Johannesburg 1984.

4. Spottiswoode, S.M., Underground Seismic Networks and Safety. Symposium on Monitoring for Safety in Geotechnical Engineering. International Society for Rock Mechanics, S.A. National Group, Johannesburg, Aug. 1984.

5. Scheepers, J.B., The Klerksdorp Seismic Network: Monitoring of Seismic Events and Systems Layout. Proceedings of the 1st International Congress on Rockbursts and Seismicity in Mines. Johannesburg, 1982. SAIMM. Johannesburg 1984.

6. McGarr, A., Some Applications of Seismic Source Mechanism Studies to Assessing Underground Hazard. Proceedings of the 1st International Congress on Rockbursts and Seismicity in Mines. Johannesburg, 1982. SAIMM. Johannesburg 1984.

7. Salamon, M.D.G. and Wiebols, G.A., Location of Seismic Events. Chamber of Mines of South Africa, Research Organizations. C.O.M. Reference - Project No. 1/134/70, Research Report No. 18/72.

8. Eccles, C.D. and Ryder, J.A., Seismic Location Algorithms: A Comparative Evaluation. Proceedings of the 1st International Congress on rockbursts and Seismicity in Mines. Johannesburg, 1982. SAIMM. Johannesburg 1984.

9. Solms, R.L. de G., Shaft Design for Western Deep Levels No. 1 Shaft Association of Mine Managers of South Africa, Chamber of Mines, Papers and Discussions 1982-1983.

10. Electrolab, Spokane, Washington, U.S.A. System Data Sheets sent to O. Momoh, Noranda Research Centre, Sept. 3, 1984.