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The Role of Computers in the Detection and Research of Seismic Events on the West Wits Line

K.L. RIEMER

West Driefontein Gold Mine, Carletonville, South Africa

The West Wits Line first began yielding gold in the mid-1930s and is among South Africa's leading gold-producing areas. Gold mining operations are carried out amidst the occurrence of seismic events which cause both damage to underground excavations and injury and loss of life to production personnel. The feasibility of establishing a system to minotor the seismicity on all the Gold Fields mines was investigated during the early 1980s. This led to the establishment of a centralized seismic network in 1981.

The system was structured around three major objectives. It uses Perkin Elmer (now Concurrent Computer Corporation) 16 and 32 bit mini-computers. The hardware in use at both the central and remote sites is outlined, giving a good insight into the role of computers in the system. The system software reveals the fast flow of data through the network; it can be divided into three categories:

(1) data logging and transmission — remote sites,
(2) data capture and communications — central site,
(3) applications and research — central site.

Several examples are given which show how the system is measuring up to its objectives. These case studies also indicate how the computers are effective in representing the seismic data collected. It is concluded that the use of computers enables the pin-pointing of seismic events on the West Wits Line within about 3 – 4 minutes of their occurrence.

The choice of hardware is largely dependent on the objectives of system, and the Gold Fields Network has chosen mini-computers because of the speed of communication and the large amount of data and storage required for research applications.

Introduction

The economic potential of Carletonville area was realized with the discovery of the gold bearing reefs of the Upper Witwatersrand series by Dr Rudolf Krahmann. This resulted in the development of the West Wits Line (Figure 1) which was to add a new dimension to South Africa's gold reserves. Mining operations in the area started in 1934 with the Venterspost Gold Mine, and today the West Wits Line is among the top producing regions of the country. Throughout its 55-year history the area has been responsible for 15 gold mining leases.[1] In addition to the high tonnages in the area, mining operations are extending to progressively greater depths, with layouts in the region of 4 000m below surface presently being planned.

One of the problems which has burdened the gold mining industry since its early days, and in which the West Wits Line is no exception, is that of rockbursts and/or seismic events. These dangerous releases

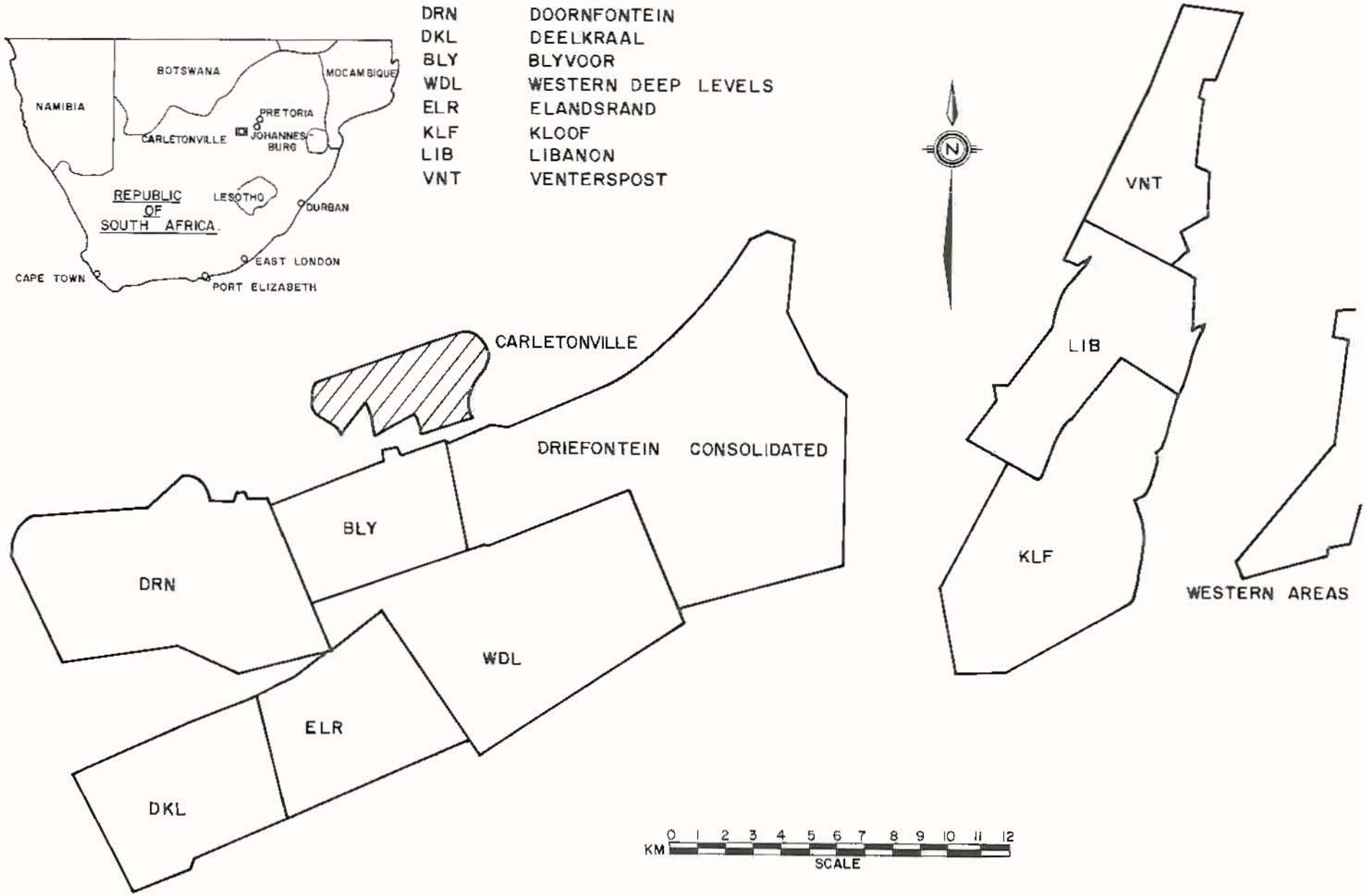


FIGURE 1. Plan of location of mines on the West Wits Line

of energy show all the properties of natural earthquakes and range in scale from micro fracturing of the rock to violent releases of energy measuring 5,2 on the Richter Scale. The events can disrupt mining operations by causing frequent damage to underground workings as well as injuries and loss of life to underground personnel.

In confronting these problems, the disciplines of Rock Mechanics and seismology have received enormous attention over the last twenty years. One of the first tasks in seismology was the location of the hypocenters of these events; this need led to the establishment of a number of seismic networks on individual mines from the late 1960s onwards. Although some of the early systems used analogue techniques, most of the subsequent systems resorted to digital methods and the use of computers to carry out seismic research.

Gold Fields of South Africa has extensive interests in the West Wits Line, and it investigated the feasibility of establishing a seismic network during the late 1970s. The purpose of this paper is to describe the application of computers and their role in the detection and research of seismic events using the Gold Fields system on the West Wits Line. The development of the seismic network is outlined together with its major objectives.

The computer hardware in use is described in some detail, and the role of the computers in terms of the applications software is then considered. Some examples are put forward on how the system is meeting its objectives, and finally various conclusions on the system and on the use of computers are outlined.

The Gold Fields Network and system objectives

When the Gold Fields Network was established, several objectives were laid down for its operation. These have been outlined by De Jongh and Klokow.[2] For the purpose of this study, they are summarized below:

Immediate objectives

It was decided that the system would function as a management tool, including the rapid location of seismic events. This facility was vital in order to implement rescue operations as soon as possible whenever the need arose.

Medium term objectives

Once the locations of seismic events had been obtained they could be stored and used to identify active geological structures such as dykes and faults. This would then assist in planning of mine layouts and remnant blocks. In addition, it was hoped that the information would provide feedback on the use of various support methods such as backfill and stabilizing pillars.

Long term objectives

Once the patterns and the occurrence of seismicity had been observed on the mine, it was hoped to be able to study in more detail the factors causing these events. This would include detailed seismogram analysis, stress migrations, laws of attenuation and in general a more detailed analysis of the wave forms.

Motivation for a seismic network within the Gold Fields Group started in about 1979 on the West Driefontein mine. During the next two years extensive work was carried out by Dr Rod Green (Bernard Price Institute, University of the Witwatersrand) and Miles Forsyth (Mining Stress Systems) on the design of the system and on the selection of suitable

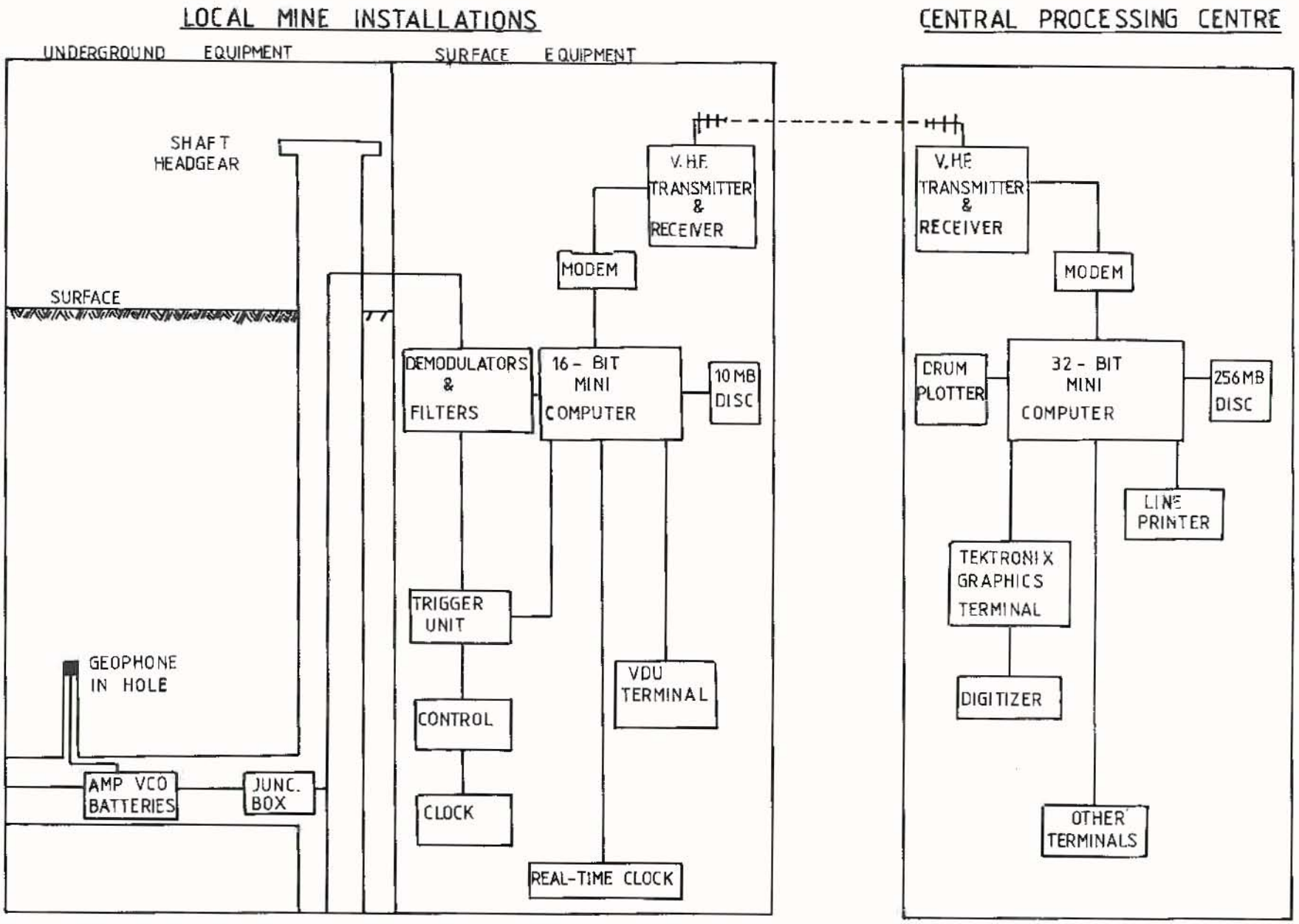


FIGURE 2. Plan of layout of the Gold Fields' seismic network

computer hardware.

During these early development stages it was decided to include all the surrounding Gold Fields Mines, and the early planning attempted to evaluate individual mine networks against one centralized system. Ultimately, from the consideration of staff requirements alone, it was decided to design a centralized system involving remote stations at each of the mines which would be linked to a central site at the West Driefontein Mine.

On the computing hardware side, the choice was not easy and had to be based on the knowledge of other existing networks. These included Hewlett Packard (Blyvooruitzicht and Western Deep Levels) and Perkin Elmer (Welkom). From the start it was clear that multiple computers would be involved: those at the remote sites would be slave systems and would need to log underground data and transmit this to a more powerful computer at the central site. Other computer hardware considered at the time included Prime and Vax, but ultimately the dual bus architecture on the Perkin Elmer hardware was considered to be a major advantage. Sixteen bit mini-computers were proposed for the remote sites, with a 32 bit mini-computer at the central site for data processing and analysis.

One other system proposed at the time was for logging at the remote sites by means of a direct memory transfer into a micro processor. The mini computers would then be used only to transfer the data to the central site. At the time this proposal was rejected as the assurance was high that the 16 bit remote computers could cope with the task.

In view of the priority to receive seismic data as quickly as possible at the central site, the communications link envisaged had to operate at high speeds. In order to achieve this, a UHF radio link that would operate at speed of 48k baud was proposed.

The eventual layout of the system adopted is shown in Figure 2. Each remote system is made up of an underground network of geophones which generate amplified and modulated signals to a surface 16 bit computer. The Perkin Elmer 1620 computer performs an analogue to digital conversion on the data and logs this to a system of files on a disc drive. The computer is also connected to a hardware triggering device which is activated during the start and end of any seismic events. Once the seismic data has been logged to disc, the 1620 computer transmits the underground data to the central site for further processing and research work. The Central mini-computer software was designed to support up to eight mines. At present it is monitoring five mines, namely West Driefontein, East Driefontein, Kloof, Doornfontein and Deelkraal. (see Figure 1).

The Gold Fields seismic network has been in operation for five years and has already recorded about 60 000 events. Seismic data is transmitted to the central site within about 1-2 minutes. In addition, messages and seismic results can be transmitted back to remote sites at will.

The features which tend to make the Gold Fields network different from most of the other existing networks are its size and also its high speed radio communications.

During the initial five year period, problems have arisen on the remote sites with both the computer hardware and software. These have generally been in the form of data losses during the logging cycle which have tended to make some data

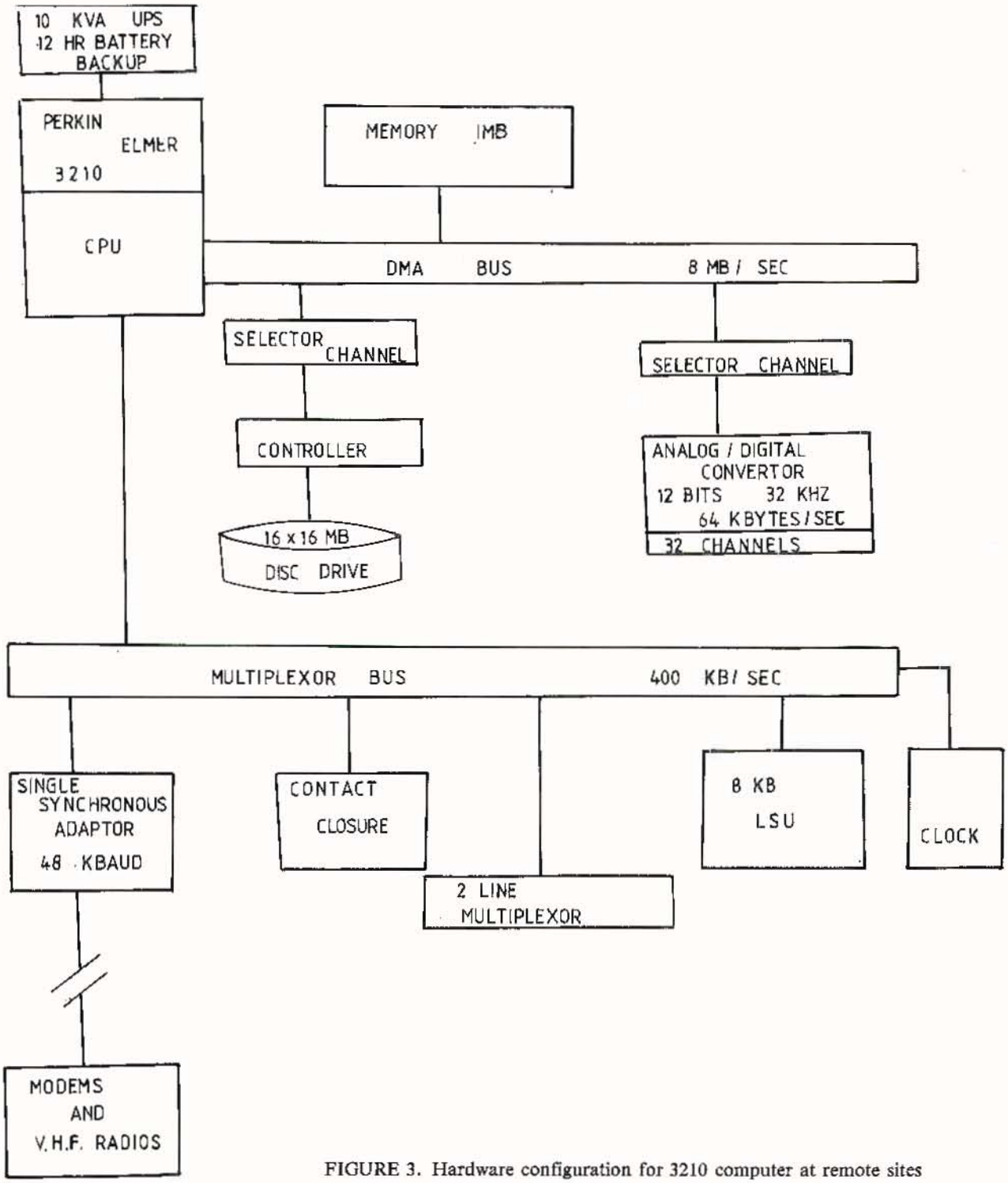


FIGURE 3. Hardware configuration for 3210 computer at remote sites

unsuitable for locating.

Changes have been carried out to the applications software, but were not successful in totally eliminating the problem. It has become evident following these changes that an upgrading of the remote site computers may be necessary.

System hardware

In the Gold Fields seismic network, computers play a significant role in terms of both speed and efficiency of handling data. In order to understand this role it is first necessary to outline the hardware used in more detail. Because the remote

1620 machines may be replaced with more powerful 3210s the remote systems will be described in terms of the latter. Some of the more important features of the Perkin Elmer 32 bit hardware are first outlined and then the system is described in terms of the remote sites, the central site and the operating systems.

The Perkin Elmer 3200 family of computers are hardware interrupt driven machines. They have four different hardware interrupt levels and can handle up to 1023 devices on these four levels. In addition, the computers have eight sets of sixteen 32 bit registers of which four are specially laid aside to support the four interrupt levels. Significant in this hardware is the dual bus architecture which includes a high speed direct memory access (DMA) bus as well as a slower speed multiplexor bus. The hardware also has high input/output band widths of 8 Mb/sec on the 3230 and processing power of 1.0 MIPS.

One of the latest developments in the Perkin Elmer 32 bit hardware has been in the field of parallel processing. These 32 bit systems can support multiple processing units under the same operating system. This gives the hardware more power by increasing the processing capabilities as well as their I/O performance. These developments are important when considering the large amount of scientific development work that must continually be performed on the hardware at the central site. Upgrades to multi processing systems are only possible from the model 3230 and upwards.

Remote sites

The hardware configuration of the 3210 mini-computer recently installed at the Deelkraal Gold Mine is shown in Figure 3. This computer is configured with 1 MB of memory and has a 16+16 MB disc drive and analogue to digital converter connected to the DMA bus. The 32 analogue channels are wired single-endedly and the conversion is 12 bits at 32 KHz. The disc drive is a fixed removable system and stores the system software and the data files for logging.

The slower multiplexor bus houses a single synchronous adapter which is connected via a V-35/RS232 modem and interface to the UHF radio link with the central site. Also connected to this bus is a contact closure detector for hardware triggering of the seismic events, a two line multiplexor board, a 8 KB loader storage unit (LSU) and a real time clock. The two line multiplexor supports a system console, and the 8 KB LSU provides a facility for loading the operating system from the disc drive. The data transfer rate on the DMA bus is up to 8 MB/sec, while on the slower multiplexor bus it is approximately 400 KB/sec. The processing power of the 3210 computer is 0,6 MIPS.

Central site

The computer hardware at the central site comprises a Perkin Elmer 3230 mini-computer with 3 MB of memory. The dual bus architecture of this computer and the configuration of its peripherals are shown in Figure 4. This central mini-computer is responsible for the data capture from the remote sites as well as development of the applications and research software.

The DMA channel supports all the on-line storage devices which includes 4 disc drives and a dual density magnetic tape drive. The operating system and system software are normally housed on a 300 MB drive. The other drives are used for compatibility with the remote sites and for data storage.

The slower multiplexor bus supports the

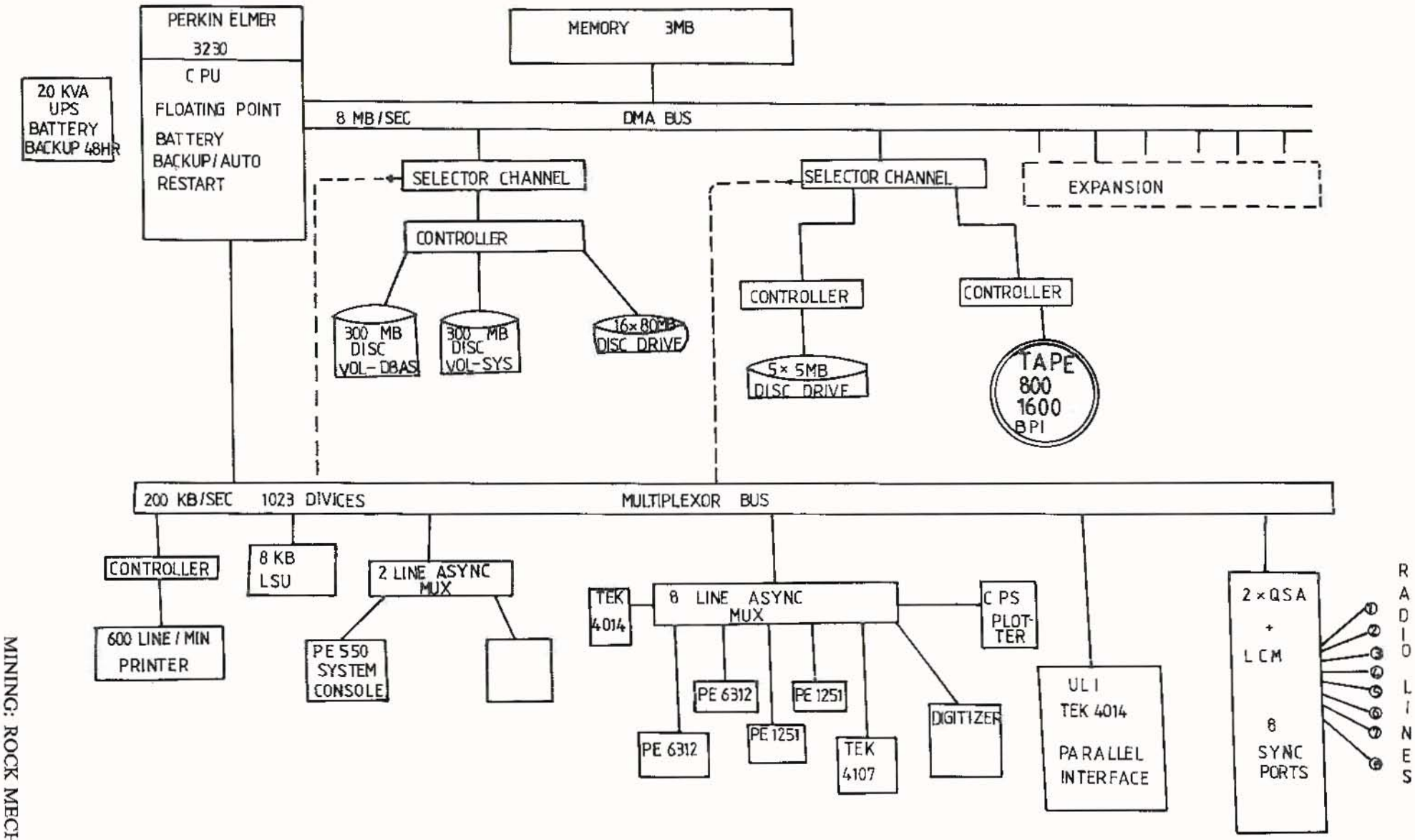


FIGURE 4. Hardware configuration for 3230 mini-computer at central site

remainder of the devices on the system. This includes the eight synchronous ports to the radios via two quad synchronous adapters and a line control module. The standard graphics and asynchronous terminals are connected via and 8 line multiplexor while a 2 line multiplexor supports a Perkin Elmer 550 system console. Printing is supported via a 600 line/min centronics printer, and an 8 KB LSU provides a facility for loading the operating system from any of the on-line storage devices.

One of the non standard features on the system is a Tektronix 4014 graphics terminal with a parallel interface and universal logic interface (ULI). Although the ULI is a standard Perkin Elmer product, the parallel interface and driver routines for the ULI were developed by the CSIR in Pretoria. This device, which is capable of operating at speeds of about 30 000 character/sec, is used in order to speed up the process of locating seismic events.

The 3230 computer is connected to a 20 KVA uniterruptable power supply with a battery back-up facility for about 48 hours. In addition to this, there is a 20 minute battery back-up auto restart facility for keeping the memory content alive.

Operating systems

Both the 3210 and the 3230 computers use the standard Perkin Elmer operating system OS/32. This is a real time multi-tasking operating system developed specifically for the 3200 series of computers which supports any of the standard languages, e.g Fortran, Cobol, Pascal, Basic, etc. In the Fortran environment its supports a universal compiler with optimizing features. Task execution and the system utilities can be controlled through the use of Perkin Elmer's powerful command substitution system. In addition, the system is easily operated and controlled through a central system console.

This gives the operator a real time task interface with control and display functions for all tasks in the system. The system can also be monitored through the use of a facility showing CPU usage, current tasks etc.

OS/32 also provides a base onto which higher level systems software can be built. At present both sites use the multi-terminal monitor (MTM). This is a time-sharing facility which is useful for controlling and scheduling development work on the systems. The MTM Facility can support up to 255 system accounts and 64 users operating from either interactive terminals or from a batch environment.

16 bit systems

The hardware configuration of the 16 bit computers, which are currently being used on four of the remote sites, although essentially the same, does have a few significant differences. The 16 bit systems also have a dual bus architecture but with much slower transfer rates of 2MB/sec and 150 KB/sec on the DMA and multiplexor buses, respectively. The 16 bit machines also use two analogue to digital converters with 16 channels per board differentially wired and driven at 16 KHz by a small external clock.

The major difference between the two computers is in the memory systems. The 1Mb in the 3210 is directly addressable while the 128 Kb on the 1620s is a paging memory system. This means that if the operating system on the 16 bit is greater than 32 Kb then these machines are effectively reduced to 64 Kb capacity, and the extended memory options are not open to the user. Disc storage on the 16 bit

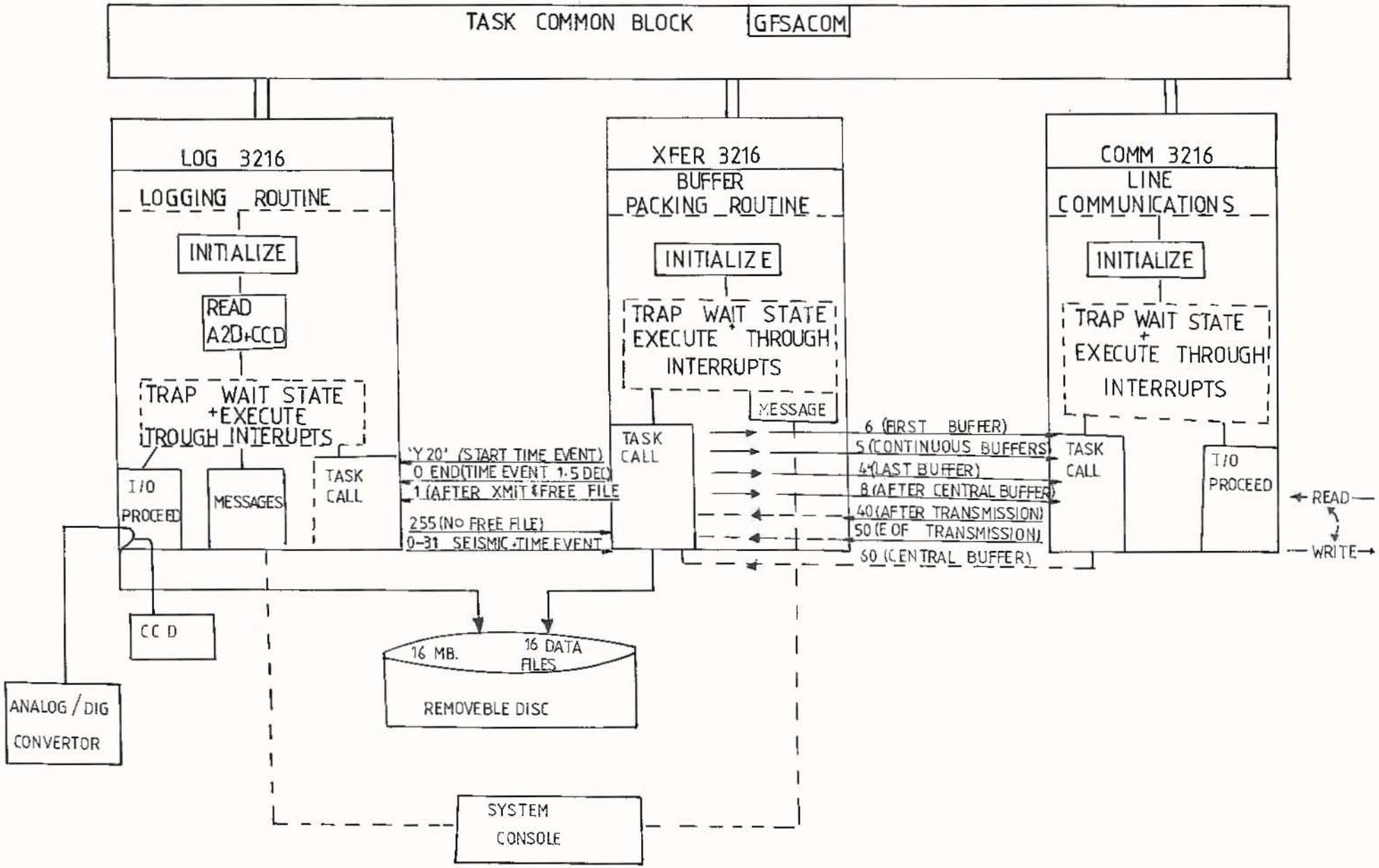


FIGURE 5. Remote site software structure for logging and data tranfer

hardware is on a 10 MB fixed/removable system. One other feature which limits the capability of the 16 bit systems is the fact that the operating system on these computers (OS/16) is no longer supported by Perkin Elmer. This came about as a major policy decision in the early 1980s and has significantly affected the adaptability of these computers to their task in the existing seismic network.

Applications software and the role of computers

The real use and application of the computer equipment in the seismic network can best be seen by examining the software configuration at both the remote and central sites. The essential functions of the systems are both the logging and fast transfer of data; the software is best divided into three categories:

(1) Logging and communications - Remote sites.

(2) Data capture and communications- Central site.

(3) Applications and research - Central site.

Once again the software at the remote sites will be described using the newly acquired 3210 computer.

Data logging and communications: remote site

The main task of the remote site computers is to perform an analogue to digital conversion on the 32 underground data channels and then log the data to files on the disc. Whenever a seismic event occurs, the computers must capture as much of the information as possible and then transfer this data at high speed (48 K baud) to the central site. In addition to the basic logging function the computers must also monitor the communications line for messages and data being passed from the central site.

Three computer programs have been established in order to achieve these goals. These are LOG3216, a Fortran logging routine; XFER3216, a Fortran buffer packing routine; and COMM3216, an Assembler line communications routine. All three programs share a common block of memory from which they access information such as input/output buffers, file flags, etc. The programs are all interrupt driven and use real time trap handling routines to execute the appropriate sub-routines when required. The task traps enabled in these programs include task calls, task message, I/O proceeds and power restorations. The basic structure of the system together with the parameters passed between the programs is shown in Figure 5.

The logging program issues reads to the analogue converter and has a read outstanding on the contact closure device in order to monitor the hardware trigger unit. The program then goes into a trap wait state and under normal conditions keeps taking I/O proceed traps from the analog converter. Logging proceeds directly to two buffers in memory that are each the same size as one physical cylinder on the disc. These two buffers are alternated, and when one is full the program writes it away to a cylinder on disc. If the status of the contact closure device does not change, the logging switches between the first two cylinders of the data file using them as a history period. If the contact closure device goes high, then logging proceeds to the rest of the cylinders on disc.

The logging routine has task communications with the buffer packing routine. Parameters are passed every time a seismic event has occurred and logging

is completed. If no free data files are found on the disc then the buffer packing is notified and logging is paused. Logging is restarted once the transfer routine has freed a data file. The only other parameters received by the logging program are those to start and end a time event. A time event is a message sent back from the central site where the first four bytes consist of the ASCII letters 'time'. Once the buffer packing sees this message, it passes a parameter to LOG3216 to commence event logging, and 1,5 seconds later passes it a second parameter to stop. The event is then handled as usual and the data is transmitted back to the central site. The time event is part of a process initiated at the central site to determine whether any remote site is in a normal working state. The logging program logs data from all the channels of the analogue converters regardless of whether or not that channel is in good working order.

The buffer packing routine when loaded goes into a trap wait state and waits for calls from either the logging or the communications routine. The program only packs channel data which is good for locating purposes through the use of 4 trigger group words in the task common block. The routine packs the data into a 512 byte buffer in task common from the relevant data file on disc, and once it has been interrupted by the logging, a series of calls and interrupts are carried out with the communications routine. The first and last buffers are always different and contain the 4 trigger group words and the end of the file marker, respectively. Task calls are also received and issued for data messages coming in from the central site. With the exception of the time event, this program will write all messages to the system console and a printing device. The routine can also receive task messages about its status from the system console, and in contrast to the logging program it assigns the data files only when required.

The line communications routine also starts in a trap wait state with a read outstanding on the communications line. Whenever event data has to be written to the line the program receives a call from the buffer packing routine and halts the read on this line and begins the transmission sequence. Task calls are received and sent back to the buffer packing, as shown in Figure 5. Task calls are also handled with the buffer packing in order to process the information being sent from the central site. This communications routine has no access to the data files on disc, and it uses the data buffers that are placed in the task common area by the buffer packing. In view of the control required on the line itself, the program is not suited to Fortran and is the only routine written in Assembler language.

The communications on the system uses a specially developed bisynchronous protocol specifically suited to the network. This was written by John Freeman (DGA) to bypass the RJE protocol initially installed on the system.

The existing 16 bit systems use similar applications software although the program structure is slightly different and all the software is written in Assembler code. Three programs, namely a logging routine (LOG16), a combined buffer packing and line communications routine (XMIT16), and a message handling routine (MESG16), are used to achieve similar results.

Data capture and communications: central site

The chief function of the mini-computer at the central site is to process the data sent to it by each of the remote sites. In addition, the central site uses a small program (TALK16) to transmit messages and seismic information back to the remote sites. All the software apart from the communications program has been written using Fortran 77; the program structure and flow of information is shown in Figure 6.

Three programs are responsible for the flow of data coming in from the remote sites, namely a line communications routine (COMM32), a file handling routine (LOG32), and a data manipulating routine (GFSA000). The first two programs share a common block of memory, and all three programs are resident in memory for 24 hour data handling. The programs are all interrupt driven in a similar way to the remote site software.

COMM32 and LOG32 work interactively during event transmission. COMM32 reads the data off the line into memory buffers, and when complete calls LOG32 to write the buffer away to a disc file. These files are the same size as the communications buffers and are built up buffer by buffer until the data is complete. Once the mine seismic file is full, a task call is sent to GFSA000 telling it that an event is ready for processing. GFSA000 uses the 4 trigger group words received in the first buffer to decode which channels are being sent and writes the channel and other information concerning the event to two files, a seismic data file (seisgram.dat) and a located information file (locatedx.dat). The located files store data for 28 000 events each and therefore form a series of files which are backed up to tape when complete. These files have a header record for each file and 256 halfwords of data for every event. The seismic data file has a 64 byte record length and stores a sample (halfword) for every channel per record. The file has a header record keeping a count of the first and last events in the file, and a header record for each event followed by the data for that event. The seisgram file is temporary in nature, and is designed to store the seismic data for a full day's events. This is done to keep access times to a minimum since it is the file from which the seismograms are graphically drawn during the locating process.

Once the day's locating has been done, the signal data for all the located events is rewritten to a larger file of similar format through an archive process. These files can grow to 680 000 records after which time they are renamed and backed up onto a single tape for research purposes (see Figure 6).

Once GFSA000 has finished the data processing a message is logged to the system console giving details of the event as known, and the event is then ready for locating and further user applications. The time lapse between the trigger unit going high at the remote site and the message from GFSA000 is about 2-3 minutes, during which time the computers have handled about 160 K bytes of data.

Applications and research: central site

The data logging and communications software at the central and remote sites show that for a centralized system the computers are efficient at transferring fairly large amounts of data. Another important advantage of using computers is seen in their speed and ease of accessing this data for various applications.

Seismic locations on some of the earlier

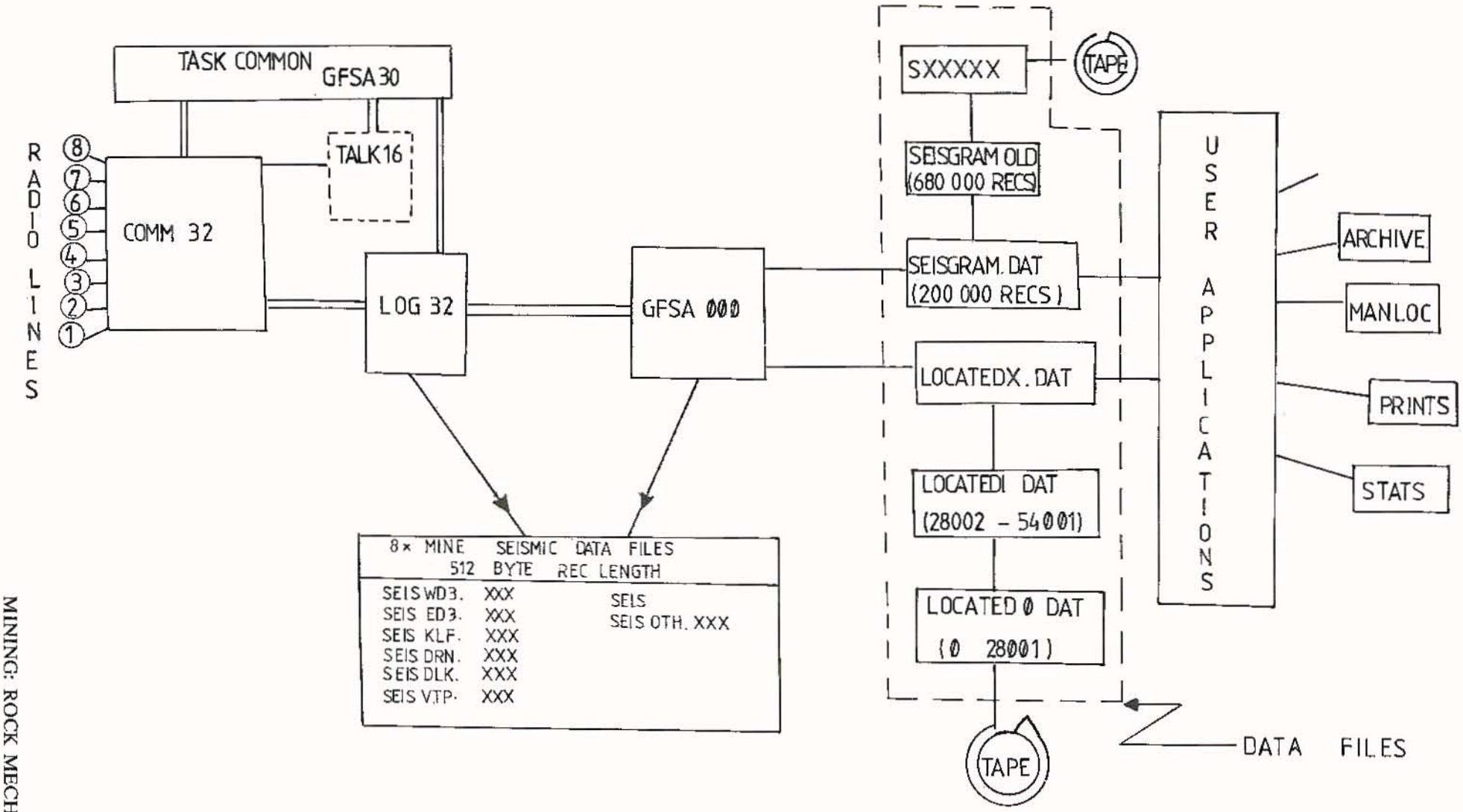
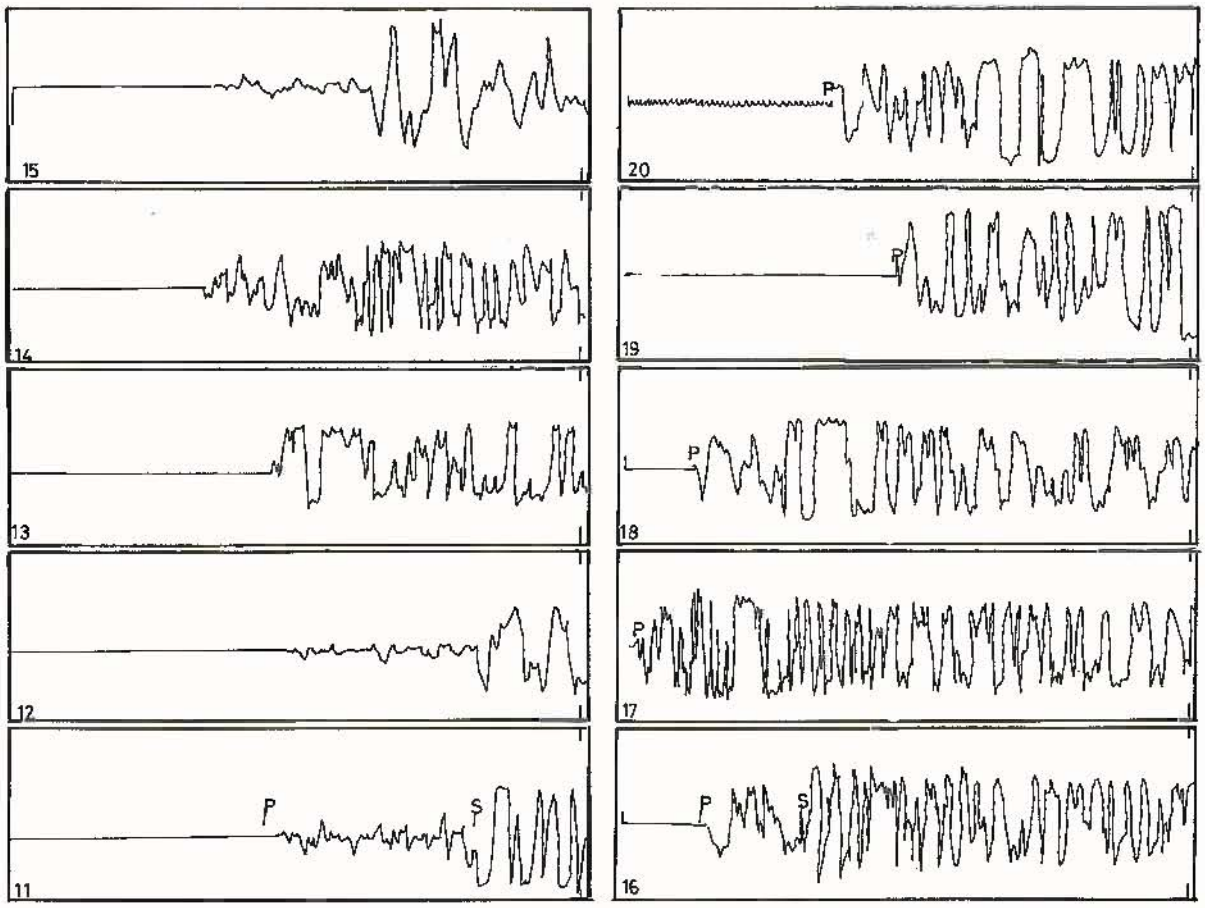


FIGURE 6. Software configuration for seismic data capture and communications at central site



SAMPLING RATE IS 838.0

EVX	EVY	EVZ	EVT	ERROR (M)
12 000	-9000	-2400	-20	
17 380	-3339	-2487	97	1470
21312	-6725	-2941	84	9477
20672	-7774	-2181	80	1220
20293	-7333	-2289	94	330
20331	-7930	-2345	79	100
20332	-7927	-2355	76	31
20332	-7926	-2357	76	27
20332	-7936	-2358	76	26

EVENT 22617 10 ARRIVALS

* * * * * * * * * * *

CHANNEL	ARRIVAL	THEOR	DIFF	VELOCITY	DIST
2P	276	276	0	5.39	1180
2S	397	399	-2	3.67	1180
7P	234	236	-2	5.96	943
7S	319	332	-15	3.88	943
10P	120	173	7	5.50	573
10S	331	233	1	3.62	573
11P	136	150	6	5.47	438
11S	137	196	-9	3.95	438
12P	113	119	-6	6.90	256
12S	153	146	7	3.38	256

EVX	EVY	EVZ	EVT	ERROR (M)
20332.	-7926	-2352	76	26

ON EAST DRIEFONTEIN
CHANNEL 12 ENERGY = 0.36674
ENTER MAGNITUDE FOR THIS EVENT (0.367)

FIGURE 7. Graphical representation of channel data for location purposes, and details of location calculation

networks,[3] were carried out using a string analogue technique. Traces of the actual seismic waves were obtained on mechanical recorders. Some of the earlier systems actually stored the data on tape and reproduced the signals on photographic paper so that events were never able to be located immediately. The string analogue was basically a scale model of the geophone array. The time differences between the primary and secondary waves were then scaled off on a length of string and the method performed a kind of manual least squares, to find the best fit for all the travel times.

Since these early days several digital algorithms have been developed for the location of seismic events.[4] These methods normally use the time difference of arrivals to set up a system of linear equations in four unknowns. A method of least squares regression is usually used

to minimize the difference between the arrivals, and because computers are so suited to this numerical type of analysis locations can usually be obtained within minutes.

The GFSA system uses an algorithm set up by Dr S. Spottiswood at Blyvooruitzicht Gold Mine, and the parallel interface used on the graphics terminal helps to speed up this process even further. Windows depicting 1 000 samples of 10 channels at a time are drawn on the screen, and the user selects the primary and secondary wave arrival times by means of a graphics screen cursor. Several options are available to the user during the selection of these arrivals and once he is satisfied, a location can be obtained in seconds. See Figure 7.

Once the located information has been stored in the relevant file, the computers are efficient at accessing and analyzing the seismic data. This is shown by the daily information which is presented to management and which is used for simple type analysis. Printouts of the located information can be obtained within minutes and simple statistics can easily be obtained from user written programs. All this information is shown in Figures 8 and 9.

These examples indicate that computers with fast processing speeds are usually well suited to the location and research of seismic events. On other systems where micro-seismic data is being processed and approximately 100 events are triggered every hour, computers are unrivalled in data handling.

Case studies

In its five years of operation the Gold fields Seismic Network has seen the inclusion of five mines. Priority has always been given to operation of the system as a management tool. This has meant that maintenance work to ensure the rapid location of seismic events has always taken priority over system development and research work. Unfortunately, the large amount of maintenance work, involving both the underground technical equipment an the computers themselves, has meant that the system has not developed toward the analysis of the accumulated data as it might have done. Nevertheless, during this time period several case histories can be highlighted which show how the development of the system can be measured against its original objectives.

On 27 December 1983 a 4,2 magnitude seismic event shook the Carletonville area. The intensity at the West Driefontein offices was particularly high, and management anticipated it to be somewhere on the mine. The seismic system was able to calculate the location and magnitude of the event within minutes. The hypocenter was located close to an area of mining on West Driefontein, and rescue operations were put into effect immediately, thus eliminating any wasted time in trying to establish the area of concern, and allowing panic reduction in distant, undamaged areas. As it turned out, this event caused underground damage to the surrounding mining excavations. Five workers were fatally injured and a total of 89 workers were hospitalized. Since this incident, several others have also occurred involving events between 2 and 4 on the Richter Scale which confirm that the system has met the required immediate objective.

The medium term objectives of the seismic network were involved with improved aspects of mine planning including mining layouts and support

LIST OF ALL EVENTS SINCE 11. 11. 86 MINMAG= -999, MAXMAG= 999 AT 08:09:28 ON 12 NOVEMBER 1986.

EVT NO	X	Y	Z	DEVIATION	NARR	ENERGY	DATE.		TIME.	MINE LOG	MINE TRIG	LEV / BLK.		
55 361	19 732	2247	-4173	192	8	0 73	TUESDAY	11/11	838	BLY	WDR	0/10	LOCATED	0
55 362	20128	- 20 697	-2404	14	8	0 12	TUESDAY	11/11	1025	KLF	KLF	0/35	LOCATED	0
55 363	0	0	0	0	0	0 00	TUESDAY	11/11	1112		DRN	0/0	CANCLLD	1
55 364	0	0	0	0	0	0 00	TUESDAY	11/11	1118		DRN	0/0	CANCLLD	1
55 365	19123	- 9 605	- 2027	52	13	0 41	TUESDAY	11/11	1408	EDR	EDR	0/53	LOCATED	0
55 366	0	0	0	0	0	0 00	TUESDAY	11/11	1439		KLF	0/0	CANCLLD	1
55 367	13 946	- 8 728	-2800	157	12	-0 92	TUESDAY	11/11	1440	EDR	EDR	0/40	LOCATED	0
55 368	20031	-20 470	-1795	42	9	0 00	TUESDAY	11/11	1445	KLF	KLF	0/37	LOCATED	0
55 369	19388	- 9 501	-2089	45	13	-0 54	TUESDAY	11/11	1543	EDR	EDR	0/52	LOCATED	0
55 370	20012	- 9 592	-2284	37	8	0 00	TUESDAY	11/11	1544	EDR	EDR	0/51	LOCATED	0
55 371	19444	- 9 598	-2115	61	16	-0 42	TUESDAY	11/11	1550	EDR	EDR	0/52	LOCATED	0
55 372	19817	- 9 673	-2802	21	6	0 00	TUESDAY	11/11	1550	EDR	EDR	0/52	LOCATED	0
55 373	20647	- 6 578	-1744	206	16	0 00	TUESDAY	11/11	1600	EDR	WDR	0/34	LOCATED	0
55 374	0	0	0	0	0	0 00	TUESDAY	11/11	1613		EDR	0/0	CANCLLD	5
55 375	19771	- 4 488	-2184	86	18	0 21	TUESDAY	11/11	1613	WDR	WDR	22/25	LOCATED	0
55 376	19282	- 8 641	- 2564	26	8	0 07	TUESDAY	11/11	1614	EDR	EDR	0/48	LOCATED	0
55 377	19244	- 9258	- 2638	110	16	0 49	TUESDAY	11/11	1615	EDR	EDR	0/51	LOCATED	0
55 378	18709	-10 053	- 2521	367	6	1 00	TUESDAY	11/11	1622		EDR	0/56	CANCLLD	2
55 379	19310	- 9543	- 2157	10	6	0 00	TUESDAY	11/11	1625	EDR	EDR	0/52	LOCATED	0

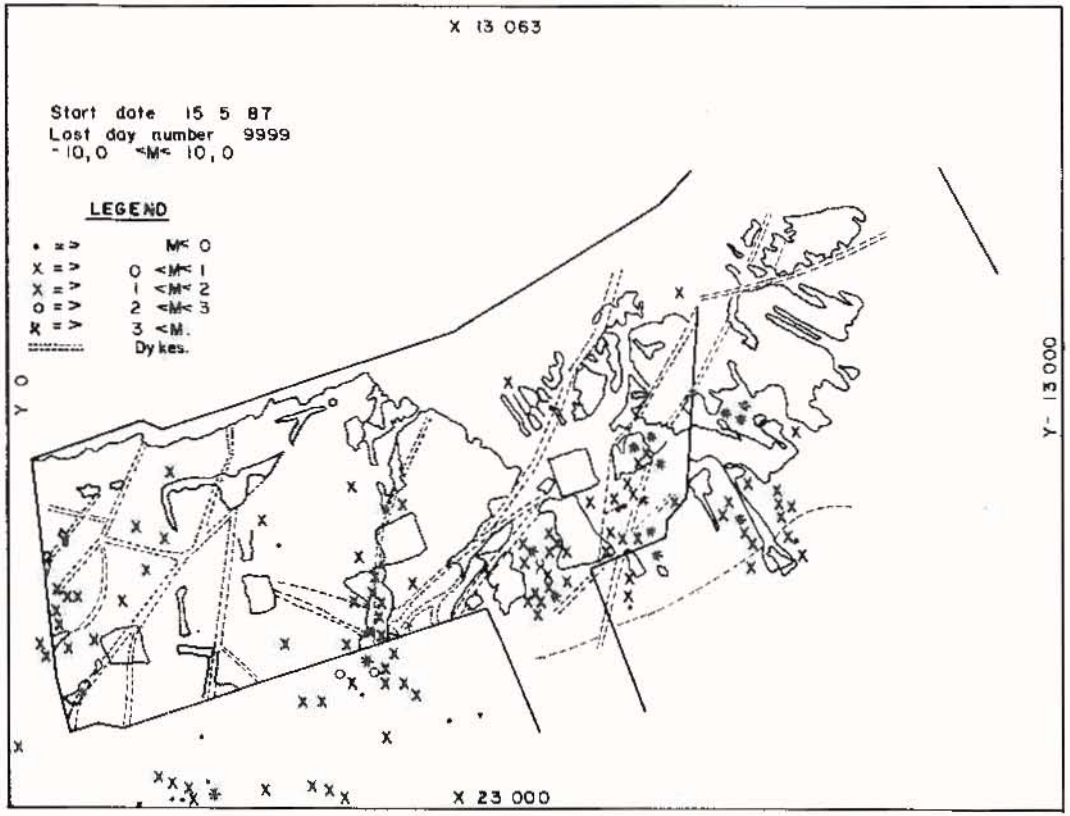


FIGURE 8. Format for printed and plotted seismic information

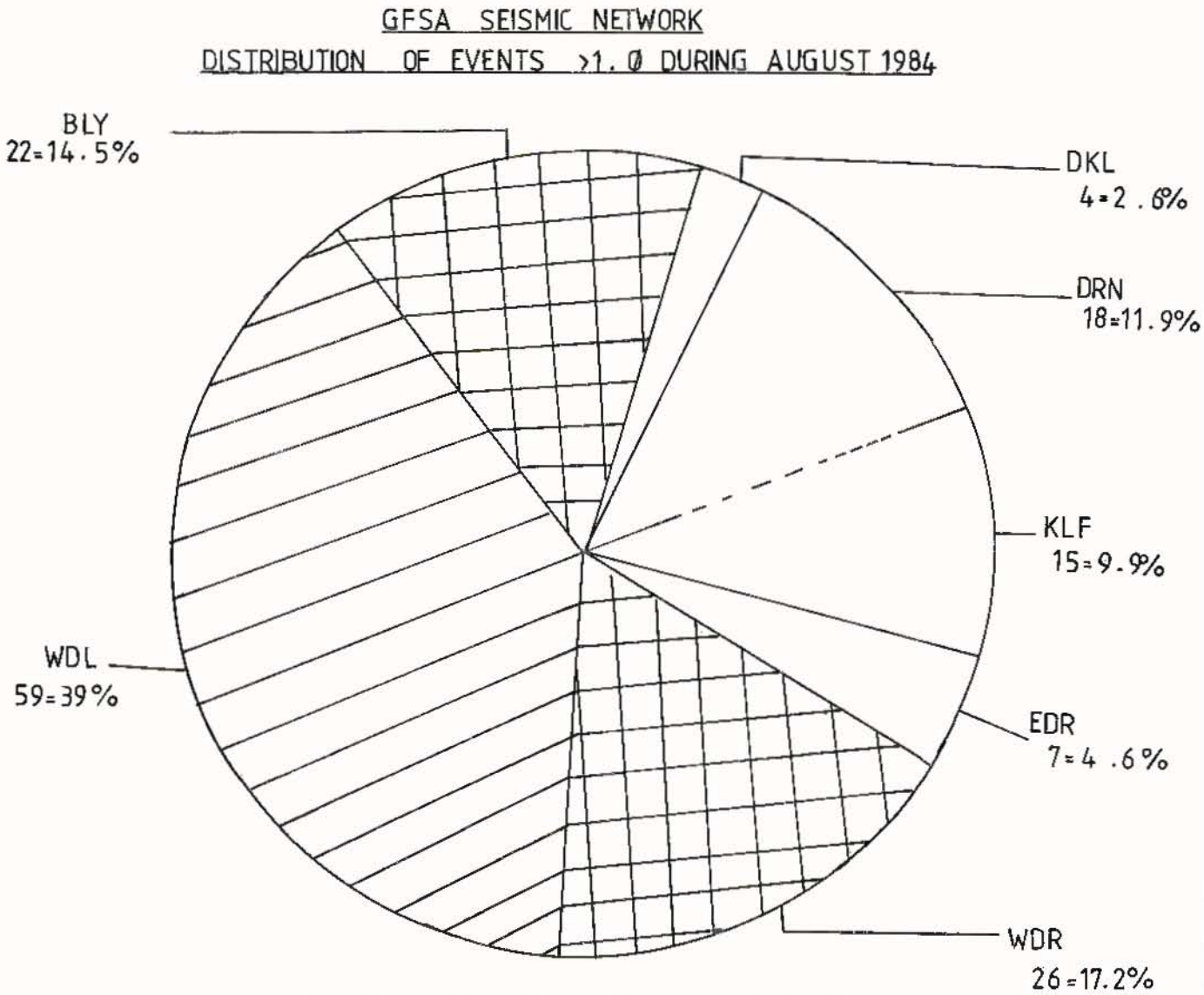


FIGURE 9. Graphical representation of seismic information

methods. Two examples have been used to show how the system is meeting some of its roles envisaged in the medium term.

Figure 10 shows the locality plan of a shaft pillar complex on West Driefontein that is presently being extracted. In July 1986 mining conditions in the area began to deteriorate, and the Rock Mechanics department was asked to investigate the methods of mining in the area. The seismic data for the area was included in a report. Prior to the deterioration the area had been mined in both easterly and westerly directions from the 14-13 Carbon Leader raise (see Figure 10). Mining in a westerly direction was progressing towards a geological fault structure and was stopped purely by accident in about January 1986 owing to labour problems. Mining was subsequently continued in an easterly direction only from February to July 1986. After this period mining was again anticipated on the westerly panels, and the Rock Mechanics department was asked to investigate the situation.

By comparing a simple plot of the seismicity during the periods 1 June 1985 - 31 January 1986 (both panels) and 1 February 1986 - 4 July 1986 (east side only, see Figures 11 & 12), the Rock Mechanics report was able to show that the

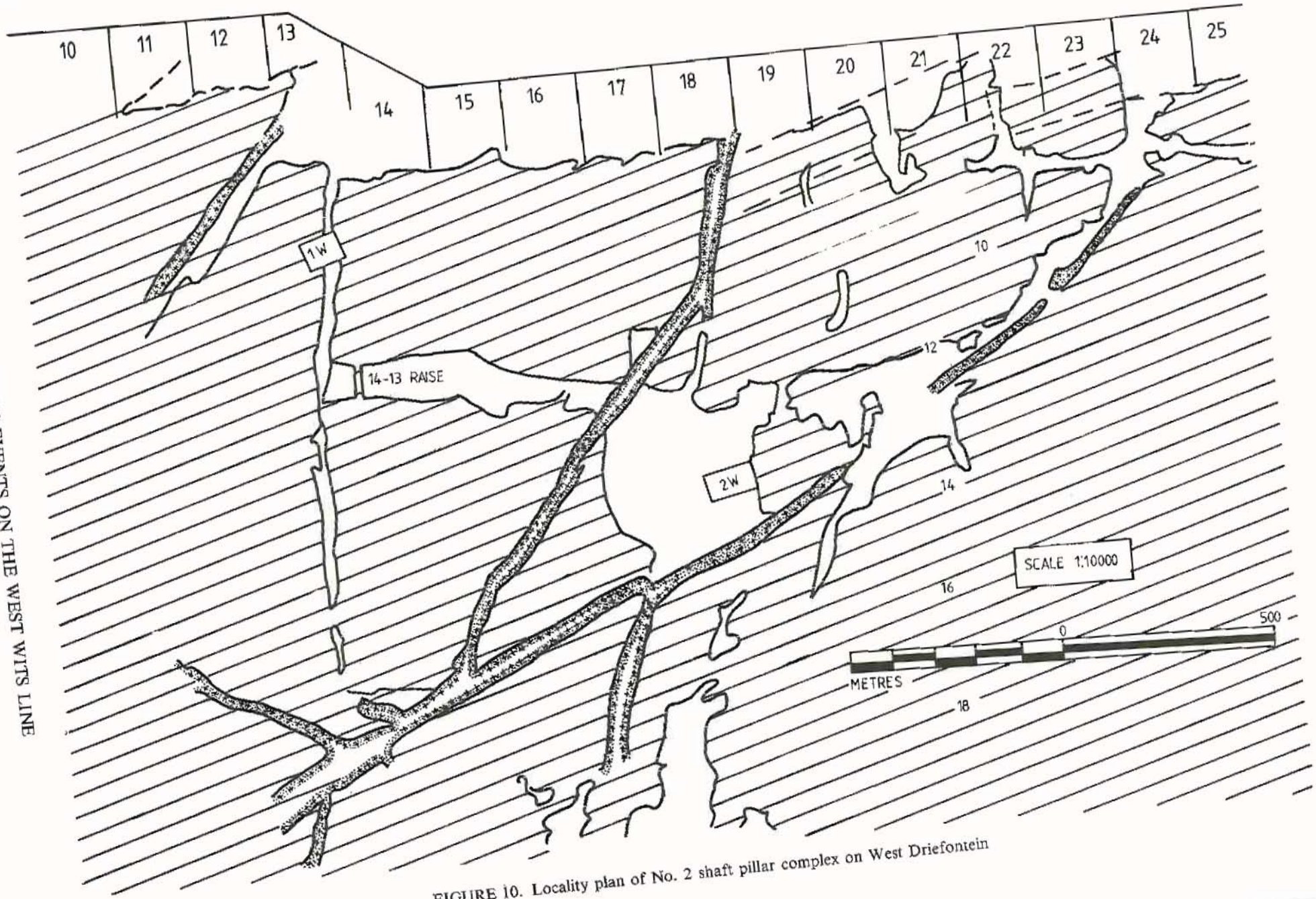


FIGURE 10. Locality plan of No. 2 shaft pillar complex on West Driefontein

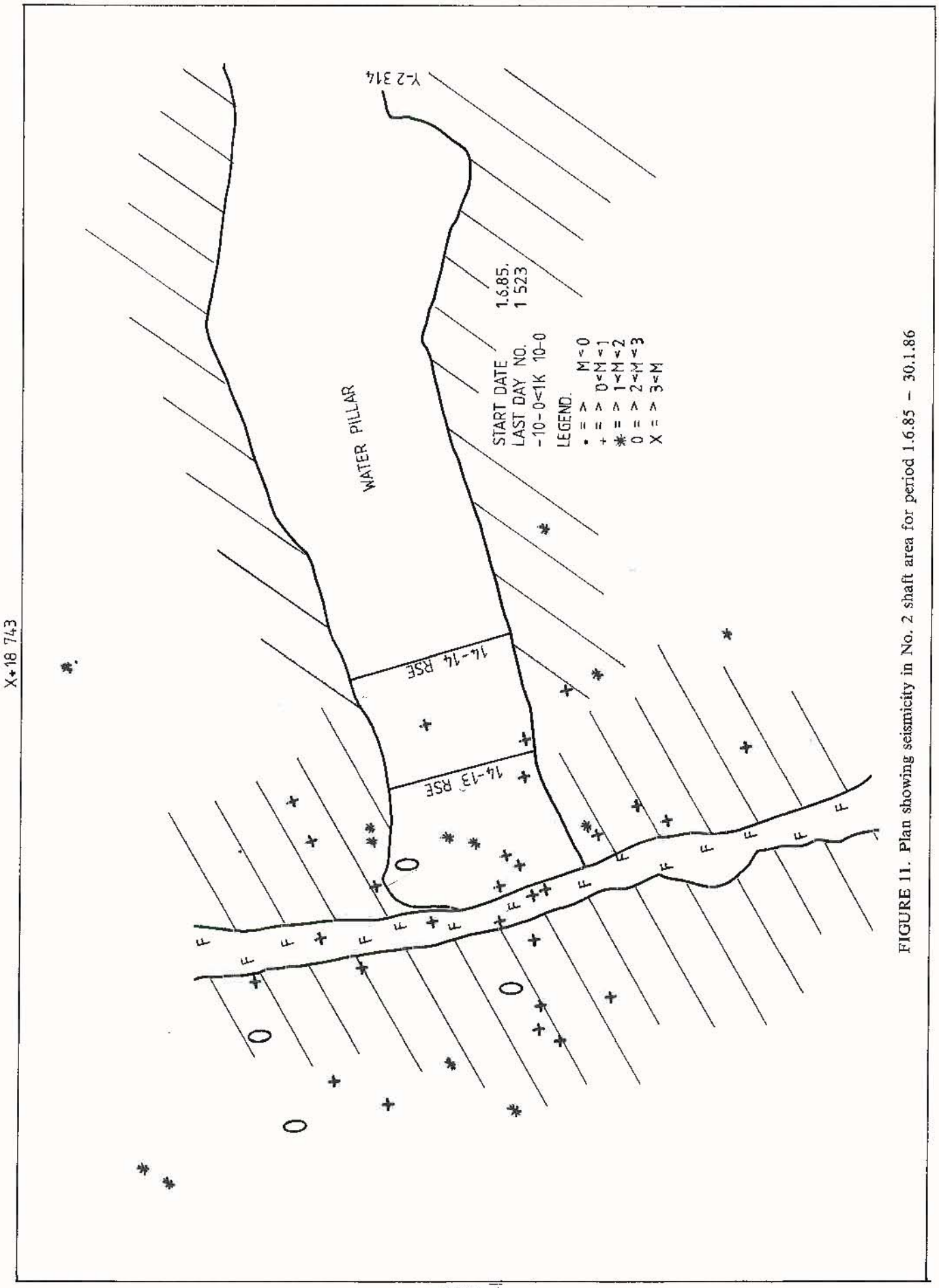


FIGURE 11. Plan showing seismicity in No. 2 shaft area for period 1.6.85 – 30.1.86

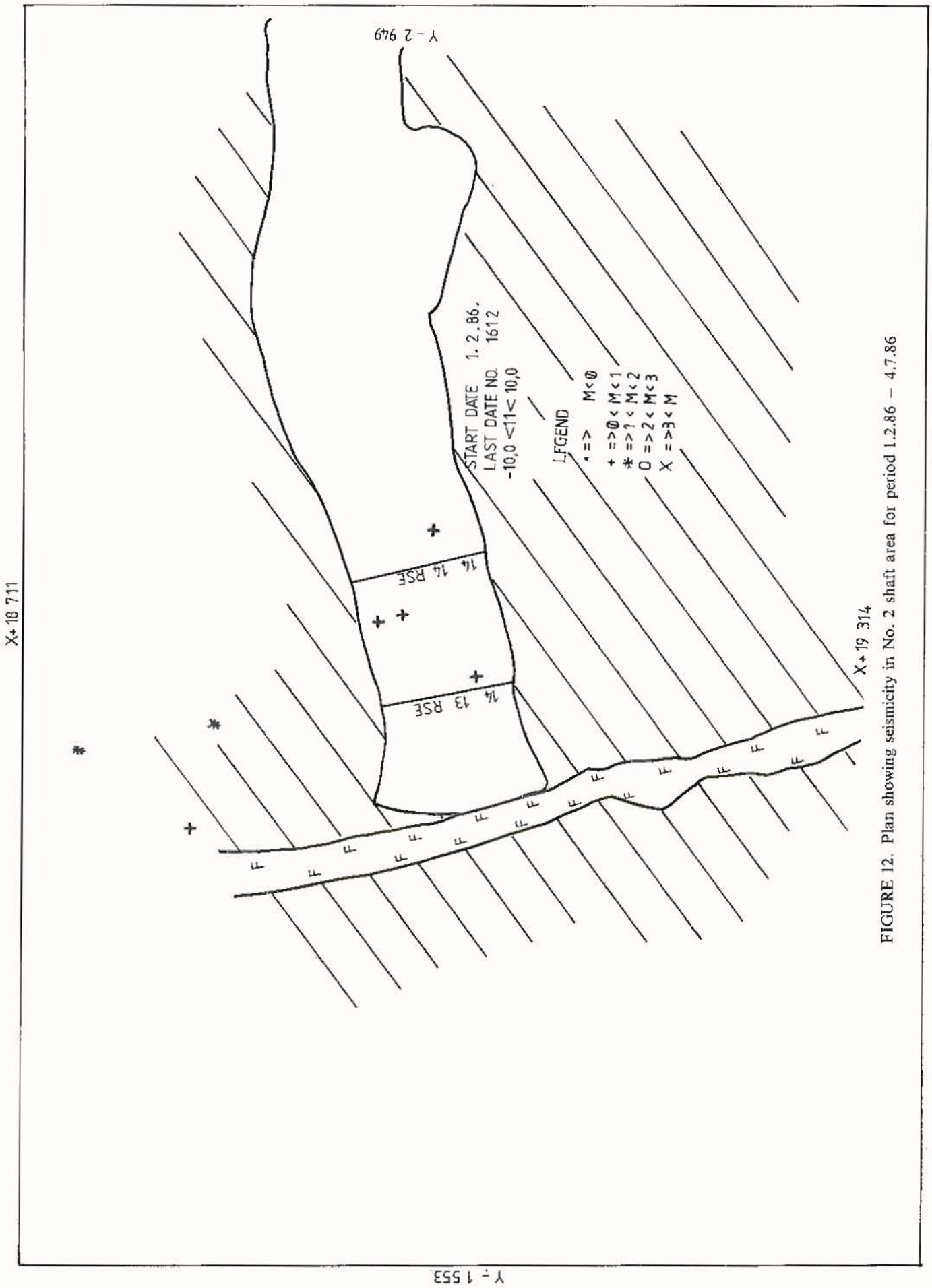


FIGURE 12. Plan showing seismicity in No. 2 shaft area for period 1.2.86 – 4.7.86

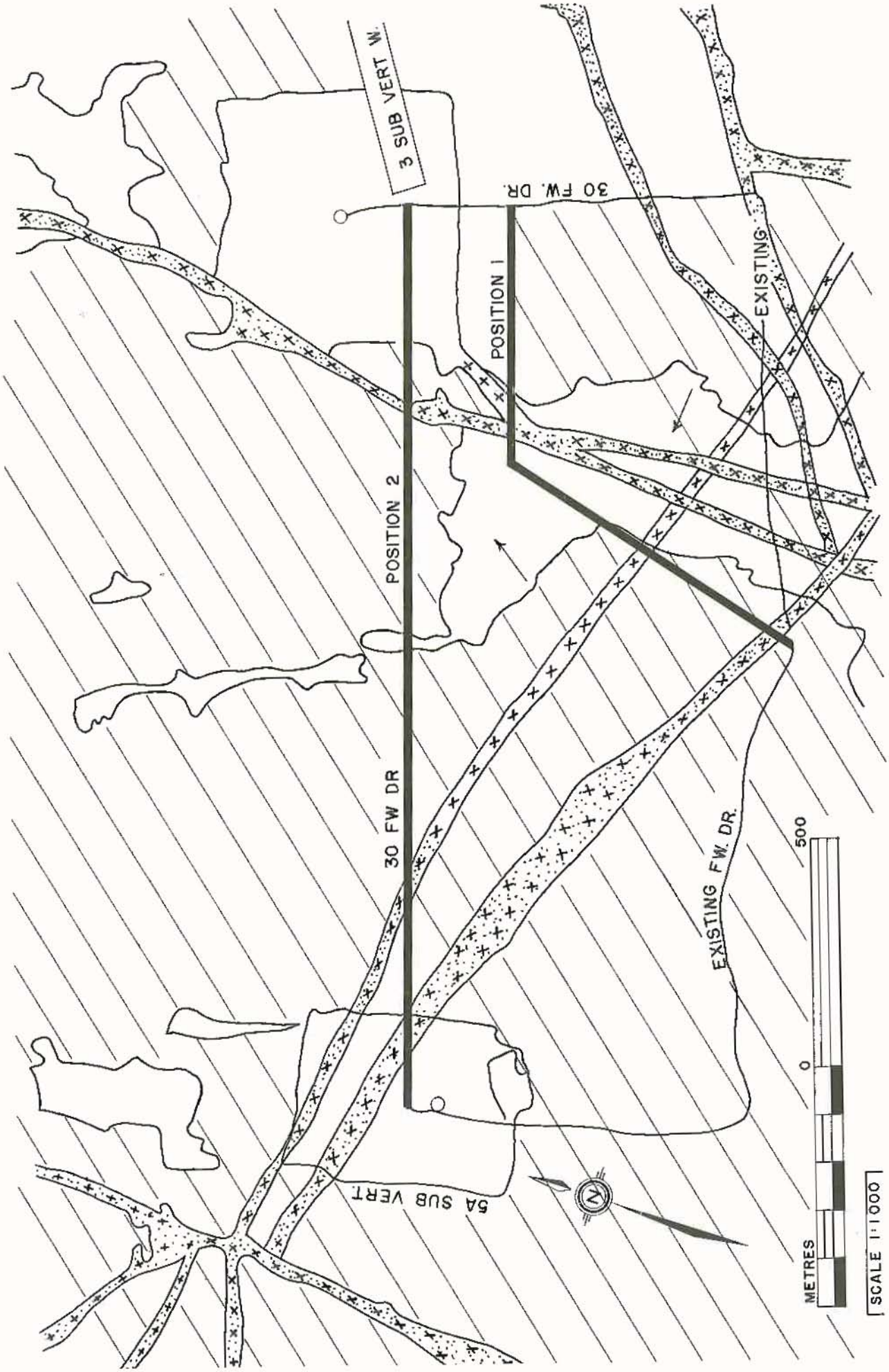


FIGURE 13. Plan of proposed positions for 30 Level haulage between No. 3 Sub Vertical and No. 5 Sub Vertical shafts

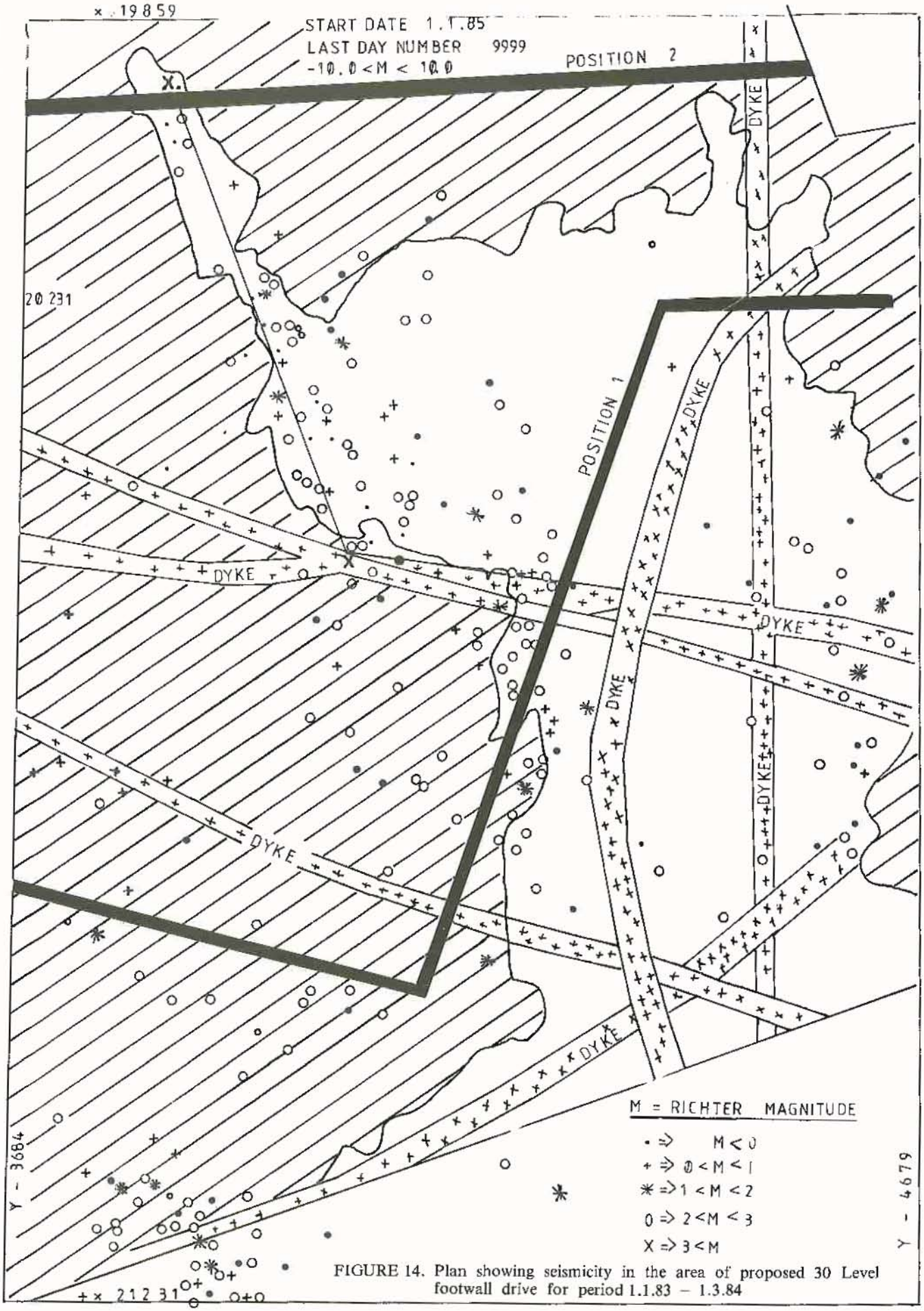


FIGURE 14. Plan showing seismicity in the area of proposed 30 Level footwall drive for period 1.1.83 – 1.3.84

westerly mining was the main cause of seismicity in the area. The recommendation put forward by the report was carried out and the westerly panels in the area were abandoned. Since this decision no furher problems were experienced in the area.

A second example is highlighted through the siting of a footwall haulage to be connected between two shaft systems on the West Driefontien Gold Mine (see Figure 13). The existing 30 level haulage connection also shown on the plan was damaged in 1984 due to a large seismic event which was located on the system of dykes intersecting the haulage. Once again seismic data was used in determining the best position for this haulage. Figure 13 shows the layout of the mining with the two proposed positions for the haulage. Figure 14 represents a plot of the seismicity in the area for the period 1/1/83 - 1/3/84, and Figure 15 a section of all the events within a 200 m radius of the line marked X-X on Figure 14.

It can be seen from figure 15 that most of the seismicity in the area was limited to within about 100 m of the reef plane. Also important in the location of this haulage was a 100 m thick shale horizon located about 100 m in the footwall of the reef. The first option for this haulage (position 1) was found to intersect the weaker shale horizon. In addition it was intersected by a complicated system of dykes and it would also have fallen under the final mining remant in the area. Consequently the second option (position 2) was chosen as it was situated much deeper in the footwall and was considered to be well out of the range of any possible seismic damage.

As far as the long term objectives are concerned, the system has not yet met any of its requirements. In recent months, a large amount of time has been spent on the development of a data base specifically for seismic research. This has involved the writing of a digitizing program that will be able to store data for any variables considered relevant to seismic research. This will include information such as geological features, sampling values, induced mining stresses, accident statistics and support types. Each of these variables will be stored in separate files on a separate disc volume. It is hoped that this base of information will help the system meet more of its medium term objectives and provide a foundation on which to base the long term research projects.

Conclusion

The Gold Fields Seismic Network was established in 1980 in order to monitor the seismicity occurring in association with the gold mining operations of the West Wits Line. The system is an example of how computers have been used to assist with a problem that causes the industry frequent setbacks. Data is transmitted from a number of remote sites to a central processing station at speeds of 48 K baud. The system uses Perkin Elmer mini-computers to achieve these goals. The speed and efficiency of the computers in handling the necessary data mean that seismic events can be located within the space of about 3 - 4 minutes. Further analysis on this data can be carried out, and several examples have been outlined to show that computers are ideally suited to this area of study.

Although the present system uses mini-computers in this particular application, it is by no means true that they are the only type of hardware suited to the task. It is possible to set up seismic systems

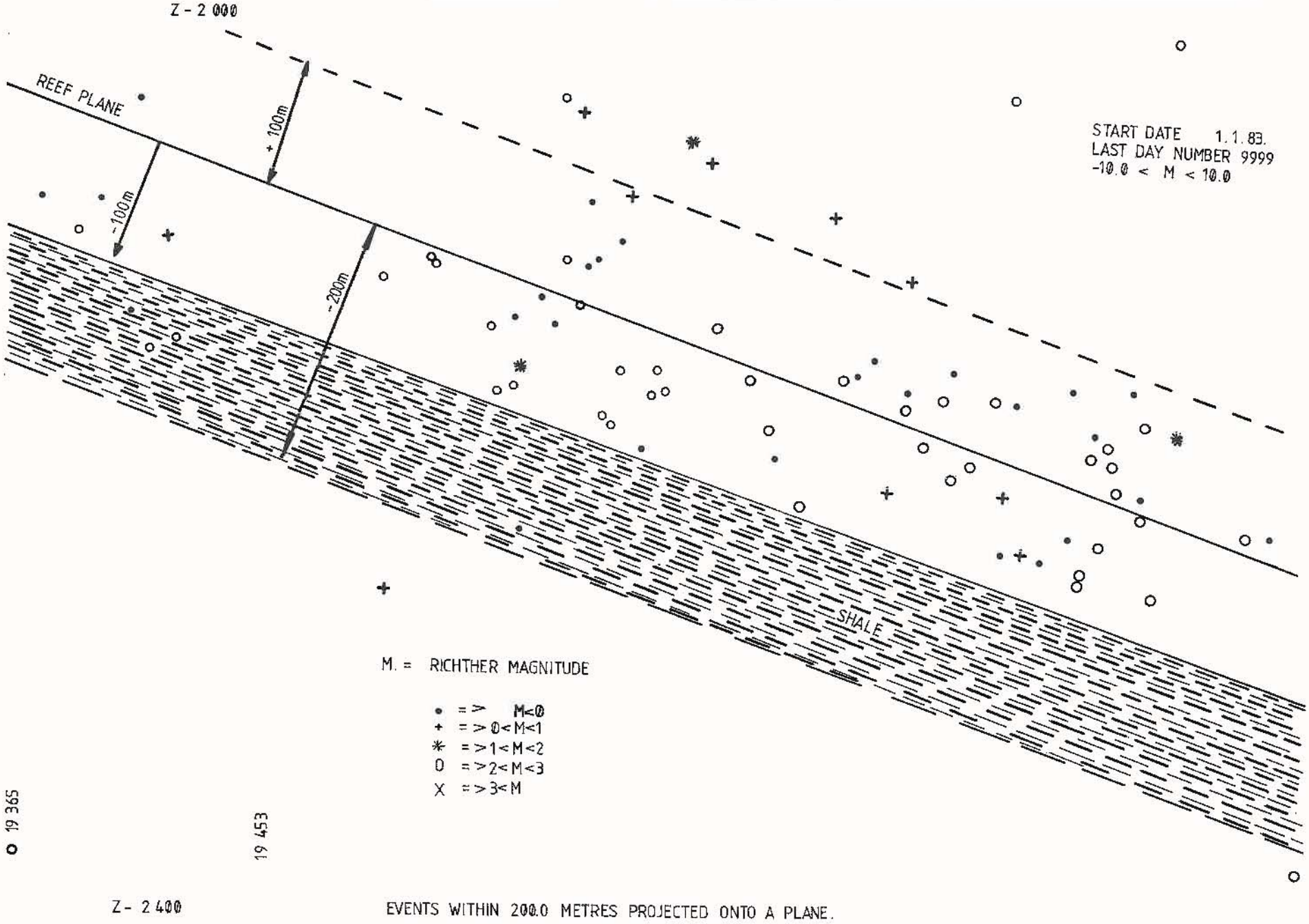


FIGURE 15. Section showing events in the area of proposed 30 Level footwall drive

using smaller micro computers. Most of the technical breakthroughs which have taken place in the micro-computer industry over the last 10 years were not available in the 1970s when most of the existing networks were designed. The type of hardware chosen for any seismic application will depend largely on the objectives of that system. The Gold Fields Network was designed as a centralized computer system because of its size, the speed of data transfers required, the large amount of data handling and the minimum staff requirement.

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