SEISMIC MONITORING OF ROCKBURSTS AND UNDERGROUND BLASTINGS FOR ASSESSING THE STABILITY OF DEEP MINE WORKINGS AT KOLAR GOLD FIELDS

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ABSTRACT:

Rockbursts (RBs) are known to occur in and around deep mines like Kolar Gold Fields (KGF) in South India, since the beginning of this century. A rockburst is characterised by a sudden collapse of excavated region because of void created during the mining operation. At large depths the problem of RB is quite severe which is a major hazard not only to mining workers, but also to property, both on surface and underground.

In order to locate precisely the sources of RBs and also the blastings in the deep mines for investigation and assessment of stability of underground mine workings, current development in seismic recording technique has been used by establishing seismic network with 14 geophones and another microseismic network with 8 high frequency geophones at KGF. These systems have been providing accurate information of the strata stability and enabled the mining engineers to assess the safety of mines more reliably. This paper summarises the details of monitoring set-up, analysis of data together with some recent results.

Key words: Rockburst, Underground blast, Stability, Safety, Monitoring

INTRODUCTION:

One of the oldest mining areas in the world is KGF, where the mining activity reached a depth of 3.35 Kms. It is situated at 100 Kms east of Bangalore in South India bearing latitude 12° 57' and longitude 78° 16'. In this area, RBs due to sudden collapse of the underground workings have been a feature of mining operations since the very early days. Some major RBs have been recorded by various seismological stations in India and the magnitude of one of the largest RB in 1973 was 4.6 on Richter scale (Guha, et al 1981). Some such similar RBs of South African deep mines have disrupted the mining operations seriously and the same could be associated with large scale rock falls, rock slips in mining horizons (McGarr, 1971). Also the intense ground vibrations may, on the other hand, cause wide spread damages to residential and other structures in the mining area (Cook, 1976). To understand the phenomenon of a rockburst, considerable research has been carried out at KGF employing various techniques (Krishnamurthy, 1969). Seismic and microseismic investigations have been carried out since 1978 and 1983 respectively for assessing the day to day stability of mine workings and to forewarn the occurrence of a RB. This paper gives an over-view of the investigations carried out for monitoring RBs and the detection capabilitilites of the monitoring systems and its applications.

SEISMIC NETWORK:

For detailed knowledge of seismicity of the area, a seismic network was established with 14 geophones, 8 on the surface and 6 in the underground. The effective regional span covered by this network is 8 Km x 3 Km x 3 Km. The analogue data from these geophones are amplified and are continuously recorded on the 24-channel magnetic tape in the central recording laboratory located on the surface. The details are published by Subbaramu et al (1985) and Murthy et al (1980). The salient features of seismic instrumentation are given in Table-I.

Table - I

Salient Features of Seismic Instrumentation

Transducer	--	Geophone
Natural Frequency	--	7.5 Hz
Response Flat	--	Upto 400 Hz
Sensitivity	--	0.33 V/cm/sec at 0.6 critical damping
Coil resistance	--	380 Ohms
No. of field sensors	--	14 Nos.
Telemetry	--	Overhead cable with carrier frequency 540 Hz for F.M.
Cable specification	--	Four-core cable with mutual capacitance 0.055 microfarads/Km
Attenuation	--	1 dB/Km
Impedance	--	400 Ohms at 1 KHz
DC resistance	--	50 Ohms
Network dimension	--	6 Km x 3Km x 2 Km.
Electronic gain	--	80 dB
Data storage	--	1" mag.tape, 24 track
Tape speed	--	15.2 mm/sec
Mode of recording	--	FM analog recording with 540 Hz centre freq.deviation of 33.3 % for input ± 5V.
Pass band of replayed signal	--	5 ~ 170 Hz.

ANALYSIS OF SEISMIC DATA:

A visual helical recorder is hooked on to one of the geophones in the seismic network. Whenever an event is detected on helicorder, the relevant portion of the tape is replayed to obtain a hard copy of all channel data . From the time lag of arrival of signal at different locations, the source is located on the basis of least square error criteria.

ACCURACY OF SOURCE LOCATION:

The accuracy of source location depends on the reliable velocity model, set of geophones and the onset of seismic signals. The accuracy of onset obtained from seismograms is ±2 ms. A set of 8 geophones covering each area are selected and respective velocity models are used (Srinivasan, 1981). The accuracy of computed source location was verified with the actual co-ordinates of rockburst damage and blast locations. A comparison of computed location with actual location of known rockbursts showed that the two differ by about 30 meters in majority of the cases as can be seen in Table - II.

Table - II
Comparision of calculated and actual source locations
(Co-ordinates in feet)

			Computed Foci			Actual Foci		
No.	Date	Time	X	Y	Z	X	Y	Z
1.	25/12/90	19:49:06	21741	4212	8833	21871	4530	8859
2.	02/07/89	22:07:20	21735	4845	9115	21815	5008	8979
3.	07/06/89	19:55:30	21880	4830	9620	22120	4990	9203
4.	04/05/88	02:29:33	10724	5831	2976	10830	6252	3018
5.	03/05/88	04:00:08	10565	5742	3182	10730	6289	3112
6.	26/08/87	19:46:21	20287	4930	9225	20780	5075	9428
7.	09/07/86	11:32:29	11337	5882	3517	11357	6240	3594
8.	17/07/85	22:55:40	11554	5900	3938	11620	6205	3940
9.	27/05/85	00:15:50	21532	4240	9239	21807	4537	9545
10.	18/02/85	15:48:07	11573	5889	3825	11661	6204	3977
11.	16/02/84	04:09:22	17765	4721	9862	17850	5180	9825
12.	11/01/82	11:54:03	28028	4126	3040	28085	3939	2898

DEEP HOLE BLAST:

The deep hole blast has been carried out in the Champion reef mine at 113 level (3.35 Kms below surface) for improving the production. This blasting is different from other usual blastings carried out on a day-to-day basis. The maximum quantity of explosive used for this deep hole blast was 1000 kg. The signals picked up due to this blasting has been made use to obtain the velocity model. The results of improved source location due to velocity model in that region are shown in Table-III.

The seismic network has provided valuable data of rockbursts ever since it became operational. More than 11000 seismic events have been recorded and their sources located. They are now available in the form of a data base. The results of the study carried out so far can be summarised as follows:

1. Rockbursts could be located precisely with an accuracy of ±30 m and informed to the mine management for necessary precautionary measure.

2. Whenever rockburst occurred, special attention is being paid to the signals coming from that region to ensure that the affected region becomes relatively quiet.

3. Investigations have also given more insight for the better understanding of their causative mechanisms.

MICROSEISMIC NETWORK:

A network consisting of 8 high frequency geophones was installed at Osborne's shaft in the Champion Reef Mine in the vicinity of 300 meters from the stoping region which is highly stressed. This network has an aperture of 500 m X 300 m from 98 to 103 levels. The geophone response of this network extends upto 800 Hz with the natural frequency of geophones at 10 Hz. The specifications of the microseismic system is same as in Table-I with the only difference in the carrier frequency of 12 KHz (Subbaramu, et al.,1985) and (Nair, et al 1989).

ANALYSIS OF MICROSEISMIC DATA:

For overall assessment of strata stability during mining operations, one possible approach is to examine the rate of microseismic signals. For such study, the demodulated signals from the field are fed to an event detector. The threshold of event detection is set manually based on ambient background noise. Coincidence of event detection for any six channels is taken as a genuine event. It is found that a rockburst is likely to occur when the rate of microseismic event is low. The event rate is found to increase after a rockburst (Subbaramu et al, 1985).

Table - III

Results of Deep Hole Blast Experiment

Date & Time	Blast Location	Velocity (Old) Kms/sec	Computed Location	Velocity (New) Kms/sec	Computed Location
23.7.85	18500	6.2	18326	5.7	18417
20:18:57	5205	5.3	5061	5.5	5095
	10515	6.6	10325	5.95	10262
26.7.85	18500	6.2	18327	5.7	18420
14:42:25	5205	5.3	5005	5.5	5028
	10535	6.6	10562	5.95	10499
30.7.85	18500	6.2	18247	5.7	18339
20:10:01	5205	5.3	5040	5.5	5071
	10555	6.6	10668	5.95	10600

SOURCE LOCATION OF MICROSEISMIC EVENT:

The source location of microseismic event is an useful parameter for assessing the strata stability. To obtain quickly the location of microseismic event, a hardware unit has been installed which determines the arrival of signals by STA/LTA criteria. PDP 11/34 computer was installed for real time acquisition of event data and for on-line estimation of the event location and focal parameters of the event. The accuracy of source location is found to be ± 5 m.

Part of the analysis is based both on the location of the microseismic events and the rate at which they occur. Analysis of the microseismic events in the deeper level suggests that (Srinivasan et al, 1993).

(a) The area associated with the mine workings exhibits normal background microseismic activity

(b) Before the major rockbursts a distinct change takes place in the microseismic event which can be scaled in terms of microseismic precursor. Abnormal increase in the microseismic activity appears to be a reliable precursor of rockburst and

(c) The spatial distribution of microseismic events tend to cluster in the region of eventual failure.

DETECTION CAPABILITIES:

With the installation of different seismic and microseismic recording systems, the signals picked up by them are analysed to obtain the information regarding the signal charecteristics and detection capabilities of the recording systems. The details are discussed as case studies:

CASE STUDIES:

1. ROCKBURST ON 9.1.1984 AT 11:26:57 HRS:

The rockburst picked up by the geophones in the seismic network is shown in Figure-1. A clear seismogram where the signal to noise ratio is found to be high in all the cases except the 5th channel (Main shaft geophone). The hypocentre is 380 m from the first arrival. The signals show down or up (compression or dilatation) first motion at different geophones. It is interesting to note that the P and S wave signals are clearly distinguishable in the case of signals from G3, G4, G5 & G7 whereas in the other cases it is not very clear.

2. MICROSEISMIC EVENT ON 26.02.1984 AT 08:43:31 HRS:

This event has been picked up by 6 high frequency geophones and two geophones in seismic network as seen in the Figure-2. In the case of signals from the 98 level to 103 level geophones, high frequency signal content of 300 Hz to 500 Hz are observed, whereas the signals at 70th and 40th levels of Giffords shaft geophones are with low frequency signal content of 50 Hz to 100 Hz. The difference of first arrival P-wave signal to the farthest geophone in the microseismic network is found to be 16 ms. The time difference between first arrival to 70th and 40th levels geophones are 130 ms 280 ms respectively. The P and S waves arrival times are clearly distinguisable in the case of 70th and 40th geophone signals. This is due to long radial distance from the source of the event. In the case of high frequency signals P-wave signal is clear whereas S-wave signal is not clear. These high frequency geophones are very close to the source.

3. DEEP HOLE BLAST ON 15.5.1980 AT 22:16:06 HRS:

This blast was carried out at the extreme north of the seismic network at Golconda shaft. The quantity of explosive used was 1000 kg and the time delays were 125 ms. The seismogram as shown in the Figure-3 was run at a chartspeed of 100 mm/sec as against usual speed of 250 mm/sec for rockburst. One geophone was installed very close to the blast location and it responded first, but the signal quality is not good due to the ground being fractured nearby. The farthest geophone in the network G1 has also picked up the signal. The P-wave signals are found to be emersive (slow rise). The signals picked up at different geophones suggest that the wave has travelled in hetrogeneous medium. The onsets of this blast signal was made use to deduce velocity model in the Nundydroog mine area.

4. BLASTING ON 12.01.1984 AT 19:51:00 HRS:

A typical blasting signal obtained from microseismic monitoring system is shown in Figure-4. The signals due to normal blasting carried out very close to the geophone locations contain high frequency content from 200 - 300 Hz. First arrival and the last arrival time difference is around 16 ms. P-wave signals are clearly seen whereas S-wave signals are difficult to be identified. In the case of blasting in mines, different time delays are used due to which different P-wave signal arrivals are seen. The P-wave first motions are seen both upward and downward.

DISCUSSION:

The seismic network has picked up 373 earthquakes of different magnitude with epicentral distances ranging from 50 to 1500 Kms. The earthquake signal picked up by the geophones are found to be feeble and the difference in P & S wave signals is clearly reflected. In the case of rockbursts depending on the hypocentral distance the P & S waves can be seen. Here, only P-wave onset is used for computation of rockburst foci as S-wave onset is not clear. Microseismic event is very close to the source and it is very difficult to differenciate both the P & S-wave signals. Similarly in the case of normal blasting and deep hole blastings different P-wave arrivals are recorded due to different time delays used in blasting. The minimum and maximum detectable seismic and microseismic signal level are found to be 0.5 to 0.3 milli-micron and 500 and 300 milli-micron respectively. The discrimination of the source, whether it is a natural earthquake or a mine induced or a man made explosion is possible on the basis of the waveform and spectral energy distribution. Suitable recording system along with proper choice of sensor facilitates the recording of signals of different frequency for discrimination purposes. In the present case, the sensor and the recording sytem have been fabricated and installed to investigate exclusively mine induced seismic events. These signals are recorded in analogue mode.

APPLICATIONS:

From the voluminous data obtained from the seismic and microseismic network, they are further analysed for delineating high stress zones in mines and developed new approaches for long-range rockburst prediction and precursor pattern for short-range prediction of rockburst. The details are described (Srinivasan, 1993) and (Jha, et al, 1993).

In order to extend microseismic monitoring to other areas prone to RB in KGF, the most recent development in the data acquisition and analysis have been incorporated in a PC-386 based microseismic monitoring system, which has been installed in the Golconda shaft of Nundydroog mine. The system installed in the underground laboratory has the capability of detecting and processing upto 30 events per minute and has a facility for monitoring the source parameters including monitoring the waveforms and the FFT of events.

National Institute of Rock Mechanics has carried out microseismic investigation at Mochia mine of Hindustan Zinc Limited, India to monitor the induced microseismic activity with a view to evaluate overall ground stability for a safe deployment of workmen. This blast was one of the largest blast in the history of underground mining in India, where 145 tonnes of explosives were used in one go to extract around 0.55 million tonnes of high grade Lead-Zinc ore. Based on the energy release rate (ERR) of microseismic events monitored round the clock in the blasted area , the routine work operations were resumed in a phased manner after 13 days, by which time ERR in various levels started coming back to the normal background rate (Jha, et al, 1994).

FUTURE PLANS:

Seismic and microseismic investigations carried out in the KGF have provided extensive database. This data will be used to determine source parameters and focal mechanism of rockburst for understanding the rockburst phenomenon and to develop a suitable deformation model. Efforts are being put to improve upon the prediction algorithms for short range prediction. Fractal character of microseismic precursor to rockbursts will be studied in detail. The PC-based microseismic monitoring system could be extended to other mining areas, hydroelectric projects, nuclear power plant sites and other areas where ground control problems pose threats to regional stability.

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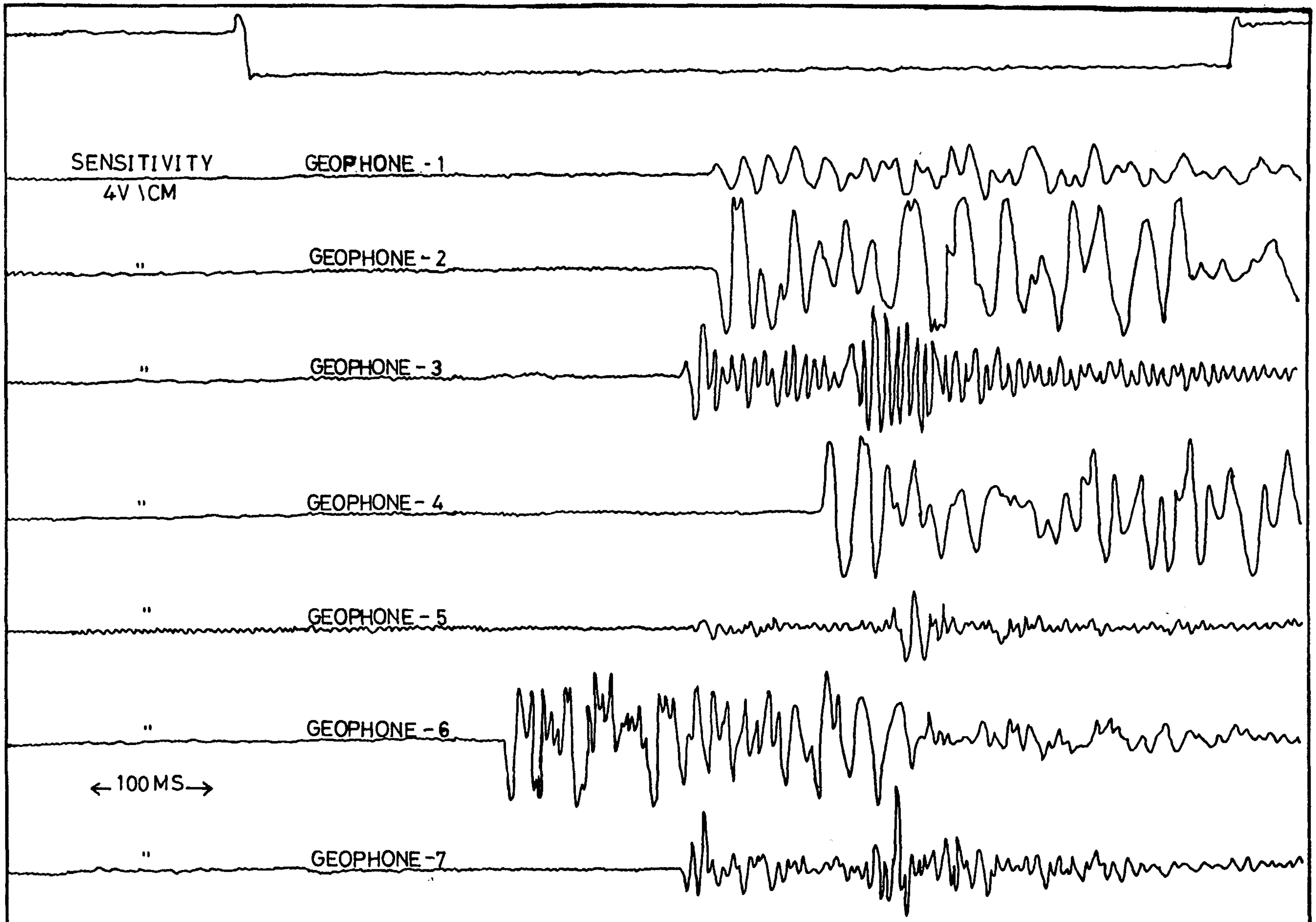
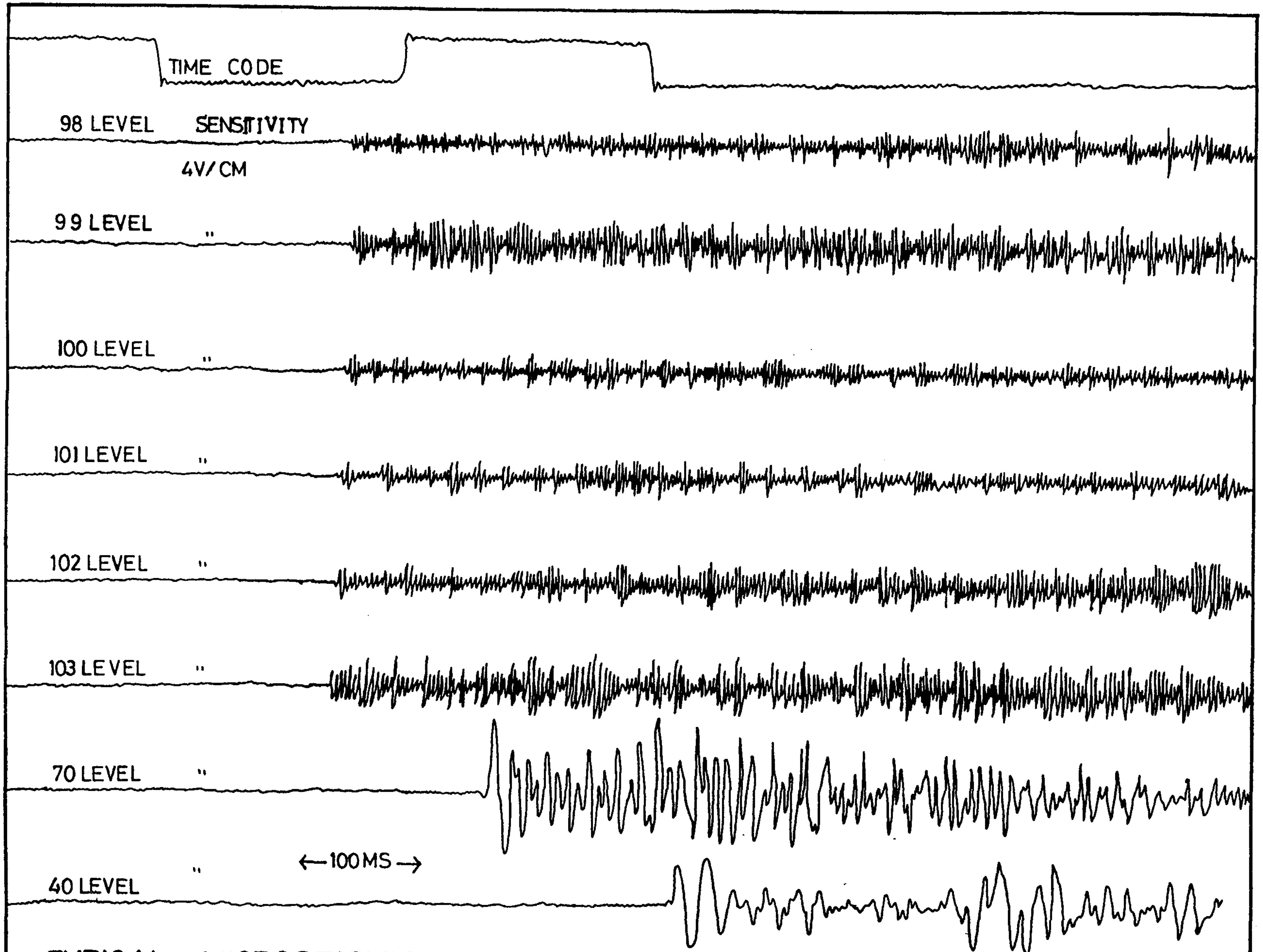


FIGURE - 1 ROCKBURST ON 9TH JANUARY 1984 AT 11:26:57 HRS



TYPICAL MICROSEISMIC SIGNAL ON 26-02-1984 AT 08:43:31 HRS

FIGURE 2

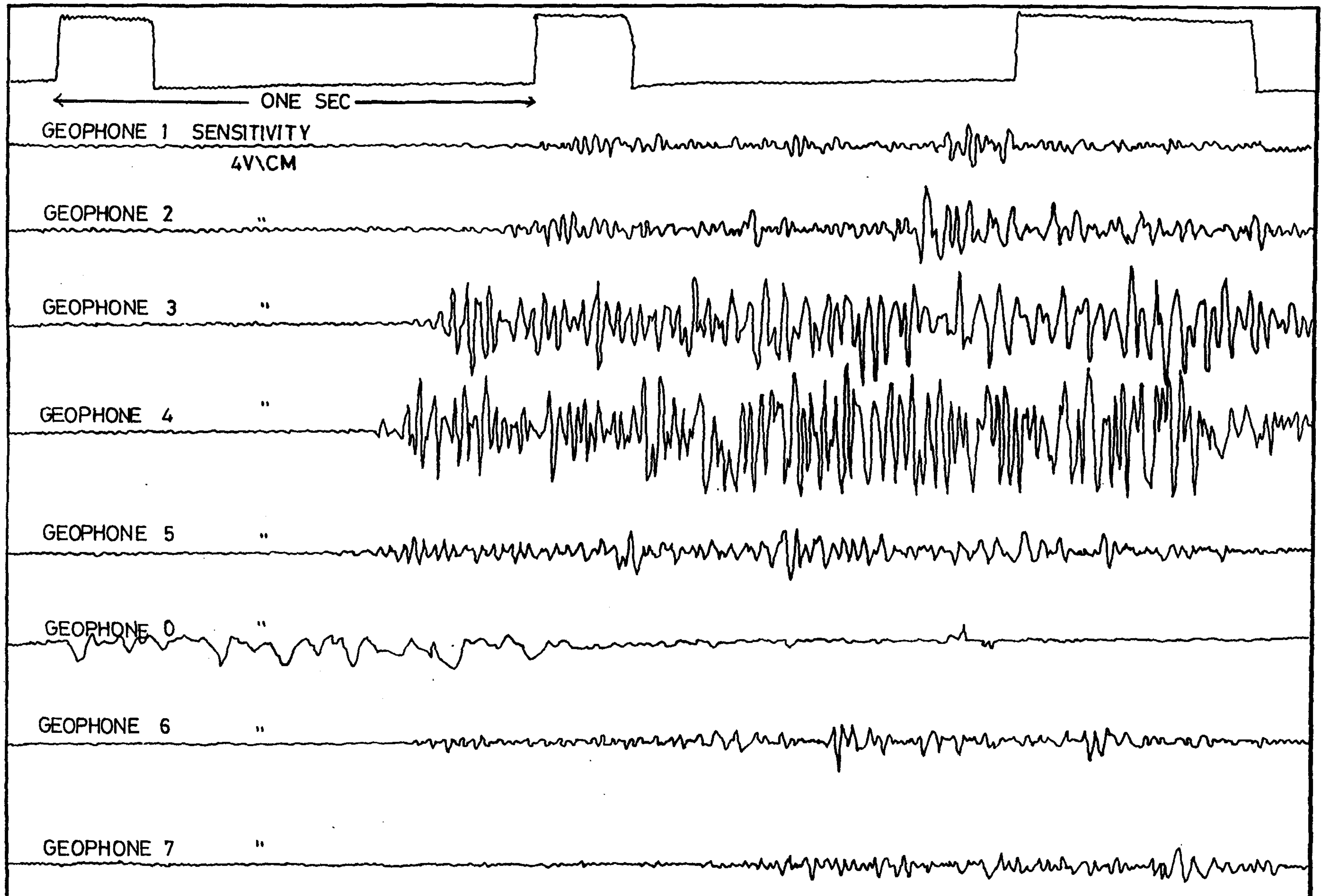


FIGURE-3 DEEP HOLE BLASTING ON 15-MAY-1980 AT 22:16:06 HRS

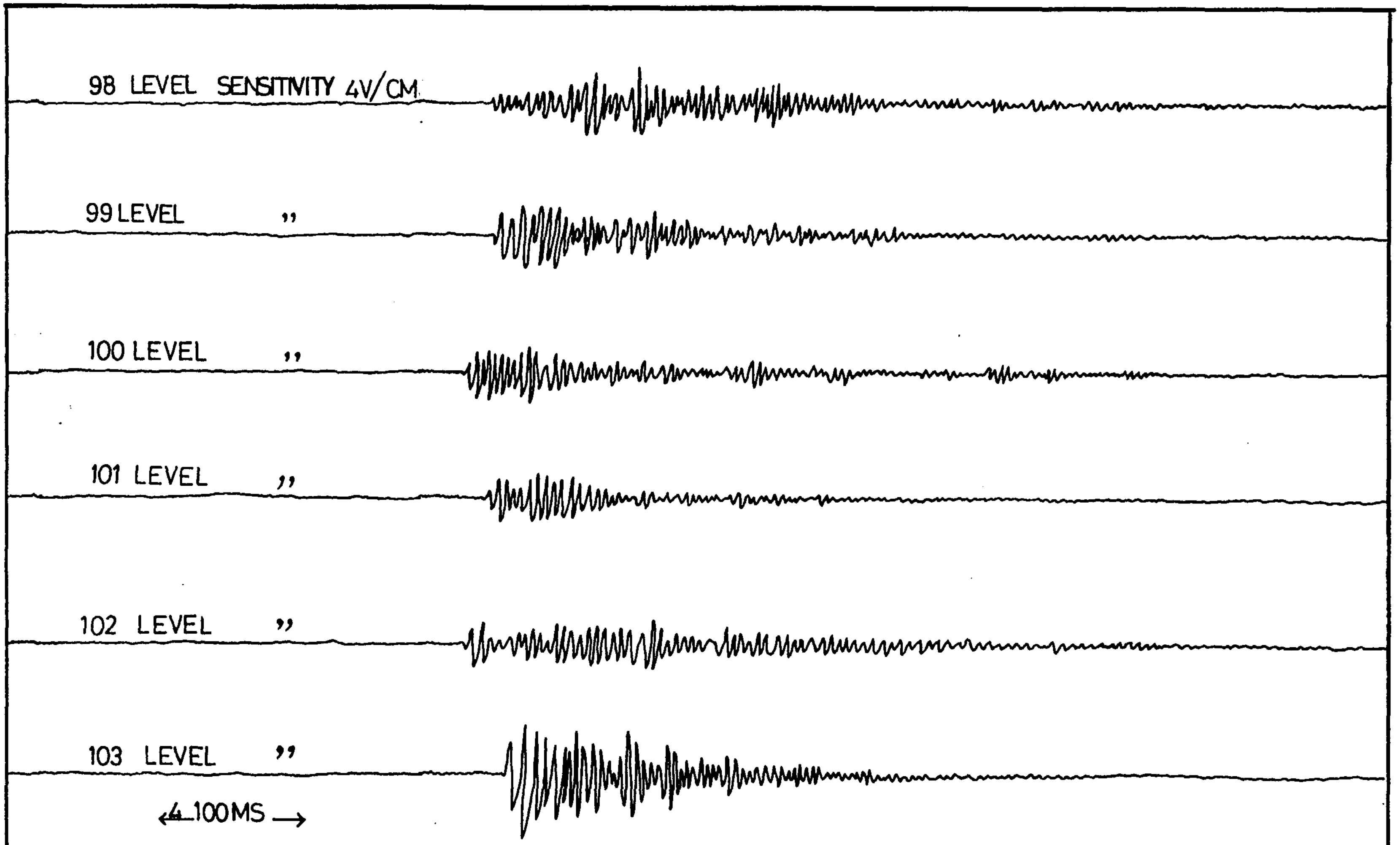


FIGURE-4 BLASTING ON 12.1.84 AT 19:51:00 HRS.