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GOOGONG DAM SITE, NSW - SEISMICITY INVESTIGATION 1971

by

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SUMMARY

The Googong dam site, near Queanbeyan, NSW, was instrumented to record local earthquakes for a period of three months (8.9.71 to 6.12.71) to provide seismicity information for consideration in the design of the proposed dam wall. During that time no events were recorded from within the future water storage area or from along the Queanbeyan Fault. Consequently recorded seismicity since 1960 is confined to one event of magnitude 2.5 (Cleary, 1967).

It is recommended that the minimum seismic magnitude to be allowed for in the design of the dam wall be ML=3 as determined by Cleary (1967) for the area as a whole. The criteria to be adopted could be the same as those used in the Snowy Mountains Scheme.

The sensitivity of the recording array was sufficient to record small quarry blasts (less than 36 kg) at distances of 10 km and microtremors, within the array, as small as ML=0.3. The survey provided a useful test of new types of instruments being introduced to BMR and it was found that constant maintenance was required for this kind of operation. Modifications would be needed for a more permanent system.

1. INTRODUCTION

Feasibility studies for the Googong dam near Queanbeyan, NSW (Plate 1), which is designed to supply water for the Canberra-Queanbeyan area, include geological and geophysical investigations by several groups of the Bureau of Mineral Resources (BMR). One such investigation was undertaken by the Observatories and Regional Structural Surveys Group and involved the installation at the dam site of a temporary seismic array consisting of five seismometers.

The purpose of the survey was to monitor seismic activity possibly associated with the nearby Queanbeyan Fault, and to provide, as dam wall design criteria, information on the level of seismicity to be expected in the water storage area when the reservoir is filled.

In the period 1960-70, recorded seismic activity in the area was confined to one event in 1961 of magnitude 2.5 (Cleary, 1967) based on the Richter (1935) magnitude scale for local tremors (ML). With high-gain seismometers on the site, it was planned to record microtremors (ML less than 1.5) for a continuous period of three months starting in September 1971.

2. INDUCED SEISMICITY NEAR DAMSITES

It has become clear that the construction of dams can lead to marked increases in seismicity. The first and classic case reported was that of Lake Mead formed by the Boulder dam (Carder, 1945). In the 15 years preceding dam construction, no earth tremors had been reported in the region; the first shock was felt in September 1936 when the water depth was 100 m; in 1937 more than 100 tremors were felt as the depth increased to about 120 m; this depth represents a load of approximately 21×10^9 tonnes. The seismic activity reached a maximum in May 1939, nine to ten months after the lake reached its normal depth of about 155 m, or a load of approximately 35×10^9 tonnes.

The accident at Vaiont Dam in Italy on 9 October 1963 highlighted the need to consider induced seismicity in both the construction and the siting of dams. At Vaiont, a landslide from Mount Toc (which rises above the lake) caused a wave more than 150 m high followed by a water surge 15 to 20 m high which breached the wall (Rothe, 1969). It was suggested that the landslide was caused when strata in Mount Toc were weakened by induced seismicity.

Other examples include Lake Kariba (Gough & Gough, 1970); Lake Koyna (Narain & Gupta, 1968), and the Greek lakes, Kremasta, and Marathon (Galanopoulos, 1967). Rothe (1968, 1969) notes that seismicity increases as a dam is first filled and after reaching a maximum, gradually subsides in the course of a few years. It is probable that for any particular dam no seismicity can be induced unless some critical load is exceeded. The minimum load reported to have caused seismicity is 2.7×10^8 tonnes at Lake Monteynard in France (Rothe, 1968); but the majority of examples involve loads in excess of 10^9 tonnes. Rothe (1969), however, correlates induced seismicity with water depth rather than with load and he notes that activity first starts at a depth of about 100 m.

The total weight of water in the proposed Googong storage area will be less than 10^8 tonnes and, since the water depth will be only 50 m (half the critical depth suggested by Rothe), seismicity would not be expected to increase when the dam is filled. However, the proximity of the Queanbeyan Fault, which will be subject to loading and lubrication, could affect the design of the dam wall. Any failure in the dam wall could lead to inundation of the town area of Queanbeyan.

3. INSTRUMENTS

The network used to monitor the Googong seismicity comprised five remote seismometers connected by land line to a central recording point (Plate 1). The seismic signals were recorded continuously on magnetic tape, and one signal was monitored visually on a Helicorder (Plates 2 and 3). A small cottage near the dam site provided both power and security for the unattended recorders. The recording hut was accessible to 2-wheel drive vehicles along a well established track, but four-wheel drive vehicles were required for travelling to the seismometer sites.

Seismometer stations

Seismometer sites were selected with the assistance of the BMR Engineering Geological Group (Simpson, 1972) to give good seismic coupling and to provide sufficient areal spread for accurate epicentral determinations.

Each recording site comprised a high-impedance (3.3 kohm) Willmore MkII seismometer (T_0 about 0.6 sec, 0.6 critical damping) coupled to a BMR TAM4 voltage amplifier. The instruments were housed in a small vault constructed of cement blocks and roofed with a concrete slab (Plate 2).

The seismometer at STN 1 (Plate 1) was provided with a calibration coil and was wired so that the instrument could be calibrated from the recording hut.

After the installation was completed some difficulties were encountered with pickup of r.f. noise from broadcast stations. This was eliminated by grounding the seismometer casing to one end of the signal coil of the Willmore seismometer, which was connected to the 'common' side of the TAM4 and hence to one of the twin signal lines.

Recorders

Two recorders, a single-channel Geotech Helicorder driven at 15 mm/min and a seven-channel P.I. 5107 tape recorder operating at 15/128 i.p.s., were used to monitor the array (Plate 2.).

Six ofthe seven tape recorder channels were used, one for each seismic station in the array and one for time signals. Each of the F.M. channels operated on a central frequency of 105.5 Hz and 1 volt r.m.s. was required for a $\pm$ 40% frequency deviation. The Helicorder input was paralleled with one channel of the tape recorder and was used to monitor STN 1.

Timing for the recorders was provided by an EMI crystal clock. Relays were operated every second, minute, and hour to apply approximately 1.3 volt d.c. to one channel of the tape recorder. Minute and hour marks were applied to the Helicorder. Clock comparisons were made using a Labtronics type 21B radio time-signal receiver tuned to VNG transmitted on frequency 7.5 kHz.

During the survey two P.I. 5107 motor drive amplifier modules failed. Power for the tape recorder was initially supplied by two 12-volt batteries, connected in parallel, on constant trickle charge; it is likely that the module failures were caused by mains voltage surges through the battery charger. Subsequently, the tape recorder battery was taken off 'float charge' and one battery was used to run the recorder while the other was being charged. No further module failures occurred, but there was insufficient survey time to test this revised procedure adequately.

Signal line

Unshielded PVC twin flex was used to connect the seismometers to the recorders. Approximately 6 000 m of wire was required for all stations. The cables were lashed to the top barbed strand of existing fences (Plate 3) near the stations, and led through tree branches to the actual sites. There was no cross-feed of signals even though four cables were closely lashed for a length of about 1 km on the same fence. A rope, drawn tight between a tree and a fence post (Plates 2 and 3), was used to support the cables above the river.

Lightning protection for the equipment was initially provided by Siemens button type discharge tubes (type A1-A350). They were connected to earth at each end of every wire so that each signal cable had four discharge tubes attached. The striking voltage of these tubes proved to be too high, and four amplifiers were put out of action by voltages induced in the cables during a thunderstorm. Consequently additional low-voltage protection was added to each cable in the form of back to back zener diodes and limiting resistors (Plate 3). No further instrument damage occurred during thunderstorms, and it is probable that the modified protection was effective.

Maintenance

Throughout the investigation it was found that constant instrument maintenance was required. Apart from the problems already mentioned (lightning damage and drive module failures) operation was hampered by cable breaks and amplifier drift.

The cable breaks occurred twice when storms brought down trees and branches across the lines. These breaks were located by tracing the cables and were then repaired by soldering (which required the carrying of heavy batteries in rough terrain). For future surveys such cables should be buried where possible.

Amplifier drift occurred at every station and was caused by variations in supply voltages. The amplifiers were at first each powered by three 8.1 volt, 1 000 milliamp-hour batteries, which rapidly deteriorated in power, probably because they had been previously stored almost to the limit of their shelf life. The replacement of these batteries (by 6.8-V, 4000 ma hr) and the subsequent gain adjustment was particularly time consuming because it involved travelling to each site several times.

4. DATA ANALYSIS

During the survey 37 Helicorder records and 13 magnetic tape records were produced. Events of interest were selected visually from the Helicorder records and were then located on the magnetic tape by audio monitoring. A paper record of the event was then produced for analysis. For example, the event A shown in Plate 5 was located on tape and played back to produce the traces shown in Plate 6 (example 3).

Three hundred and thirty events (omitting teleseisms) were visually detected on the Helicorder records; of these, 144 were considered to be local and were located on magnetic tape for playback. After high-speed playback the P and S phases could be resolved and those events which showed more than 2 seconds difference between P and S travel times (i.e. events further away than 10 km) were discarded; it was considered that microtremors beyond this range would have little effect on the proposed dam and events greater than ML=2 would be recorded by the permanent seismograph stations. Finally 65 events remained for further analysis.

If the P and S phase arrival times (Tp and Ts respectively) are known for a particular tremor then the origin time (To) of the event can be determined if a value of Poisson's ratio (σ) is assumed. Putting $\sigma = 0.25$ we can write.

$$Vp = Vs\sqrt{3} \qquad (1)$$

where Vp and Vs are respectively the P and S phase velocities. From equation (1) we derive

$$ts = tp\sqrt{3} \qquad (2)$$

where tp and ts are respectively the P and S travel times.

Now, defining $\Delta T = Ts - Tp$ (3)

we get $tp + \Delta T = tp\sqrt{3}$ (4)

or $tp = 1.366\Delta T$ (5)

For the chosen events the arrival times of the P and S phases for all stations are listed in Table 1. By using equations (3) and (5) the P-wave travel-times can be determined and the origin time of the event is then calculated for each station according to the equation

$$To = Tp - tp \qquad (6)$$

Because of the difficulties in picking the S-wave arrivals, the calculated origin time of the event will in general vary from station to station. The adopted origin time was taken to be the mean of the individual times. P-wave travel-times for each station were then recomputed from equation (6) using the calculated average origin time.

In general, the apparent velocity across the array was small (less than 6 km/s) for nearly all the selected events. So as a first approximation all events were assumed to occur at the surface, and, for the purpose of this interpretation, a simple geological model was assumed for the area; this consisted of a single refractor with P-wave velocity 6.5 km/s, and a delay time of 0.6s. So the distance to the event was calculated by subtracting 1.2 from the recomputed travel times and multiplying by 6.5 (Table 2). Epicentres were determined by intersecting arcs and are plotted in Plate 8.

Errors

An event known to be an explosion from a nearby quarry was analysed in the above fashion and its epicentre was located 0.2 km from the quarry. Three other events were located close to the quarry but were displaced tangentially up to 1 km from the quarry site.

For all observations, the average error between the calculated and adopted origin times was 0.06 seconds with a standard deviation of 0.09 seconds. Applied to the above geological model, this standard deviation in origin time represents an error in distance of 0.58 kilometres.

The error in epicentre location is difficult to formulate because for each event the several arcs of distance do not in general intersect at a unique point, and, since the recorded events originate well away from the array, the angles of arc intersection are acute. However, some estimate of location error can be made if each of the five distance arcs (to a particular event) is varied within the distance error 0.58 kilometres obtained above. For an event roughly 6 kilometres distant from the array, this procedure causes a radial error of 0.4 kilometres and a tangential error of 1.6 kilometres. At 10 kilometres from the array the tangential error increases to 2.0 kilometres.

Discussion

The events located and plotted in Plate 8 are most probably associated with quarry work. There are three main groups of epicentres, A, B, and C, each associated with known quarries. Records were kept of most major blasting operations in area B so that these events (about thirty) were eliminated from the analysis; however no such records were kept for the quarries in A and C. The group A may also be associated with the Deakin fault because the epicentres in this group consistently lie to the south of the known quarry, with no scatter to the north. However, the similarity between individual records (Plates 6 and 8) indicates that a constant source mechanism is responsible for these events and that the southerly bias is a result of some systematic error in plotting. The events in group D may be natural but the records from which they were read were of low amplitude and they could be incorrectly positioned group-B events.

No events were located within the array, even though microtremors of magnitude as low as -0.3 could have been detected (Appendix 1).

5. CONCLUSIONS AND RECOMMENDATIONS

In the period September to December 1971 no seismic activity was recorded from within the Googong water storage area or from along the Queanbeyan Fault. Thus the only definite conclusion to be reached is that for this area the recurrence time of seismic events (ML greater than - 0.3) is greater than three months.

Because the Googong storage area borders the Queanbeyan Fault, which Cleary (1967) proposed as a boundary of a wedge structure undergoing NW-SE compression, it is possible that seismicity could be induced by a depth of water considerably less than the 100 m quoted by Rothe (1969). Consequently it may be useful to monitor the seismicity of this area when the storage area is being filled.

Although no microtremors were recorded during this investigation it is possible that the Queanbeyan Fault will become seismically active under load and lubrication; consequently, recommendations concerning dam wall design are difficult to formulate.

The only recommendation that can be made is that the design specifications should incorporate the possibility of earthquakes at least as large as the magnitude ML 3 events recorded by Cleary (1967) for the Canberra-Gunning area. The seismicity criteria considered for the Snowy Mountains Hydro-electric Scheme dams should also be considered relevant to the Googong dam design.

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APPENDIX 1 : DETERMINATION OF MAGNITUDES

Because Willmore seismometers were used in this investigation, instead of the standard Wood-Anderson type, a calibration was required before magnitudes could be assigned to the recorded events.

Richter (1935) defined a magnitude scale based on the formula

$$ML = \text{Log } A - \log A_o \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where A is the trace amplitude from mean to peak (mm) recorded on a standard Wood-Anderson seismograph, and A_o is a standard amplitude which varies with distance. Now the amplitude (A_G) of any given event recorded at the Googong array can be related to the standard instrument amplitude (A) by

$$A/V = A_G/V_G \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

where V and V_G are the magnification factors of the standard and Googong instruments respectively. Substituting equation (2) into equation (1) :

$$ML = \log A_G - \log A_o + (V/V_G) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

or at a particular distance

$$ML = \log A_G + K \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

where K is a constant.

The constant K in equation (4) was obtained by plotting log A_G against Richter magnitudes ML (ANU), obtained from events in the Gunning area and recorded by the Australian National University (Plate 9). Events of magnitude greater than 2.8 were not plotted because they caused full-scale deflections of the recording pen at the Googong array. A least-squares fit to the plotted points gave the equation.

$$ML\ (ANU) = 0.939 \log A_G + 0.984 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

but to obtain the form of equation (4) the gradient was modified and the relation was then

$$ML\ (ANU) = \log A_G + 0.925 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

For the Googong array, $-\log A_o = 2.9$ for events in the Gunning area and since, in equation (4), $K = -\log A_o + \log (V/V_G)$, equation (6) can be rewritten as

$$ML = \log A_G - \log A_o - 1.98 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

Consequently, Richter magnitudes (ML) can be assigned to any event recorded at the Googong array by using equation (7).

Assuming that the smallest detectable amplitude (A_G) on the Googong records was 2 mm, then the smallest seismic event which could be recorded from within the array ($-\log A_o = 1.4$ at zero distance) would have magnitude $ML = -0.3$.

TABLE 1

ARRIVAL TIMES AT FIVE RECORDING STATIONS FROM SELECTED EVENTS

DATE	HR MIN	STN 1		STN 2		STN 3		STN 4		STN 5		Average origin time
	U.T.	Tp	Ts	Tp	Ts	Tp	Ts	Tp	Ts	Tp	Ts	
15/9	1535	53.65	54.77	53.14	54.86	53.14	54.83	53.24	55.03	53.34	55.23	51.92 s.
15/9	0609	51.30	52.80	51.40	53.00	51.38	53.04	51.48	53.13	51.60	53.32	50.24
17/9	0656	17.26	19.08	17.34	19.24	17.33	19.20	17.45	19.44	17.56	19.56	15.99
18/9	0203	06.92	08.50	06.99	08.67	06.99	08.65	07.09	08.82	07.20	08.73	5.84
19/9	2225	24.05	25.61			24.11	25.81	24.21	26.06	24.34	26.19	22.90
27/9	0602	12.93	14.11	13.03	14.17	13.04	14.18	13.15	14.31	13.24	14.44	12.22
30/9	0414	35.76	37.5	35.92	37.75	35.92	37.80	36.03	37.94	36.10	37.98	34.59
29/9	0415	35.68	37.20	35.74	37.5	35.74	37.39	35.84	37.63	35.94	37.74	34.54
29/9	0421	50.67	52.22	50.74		50.74	52.43	50.84	52.63	50.94	52.74	49.55
30/9	0250	49.01	50.73	49.09	50.87	49.08	50.93	49.18	51.03	49.26	51.18	47.79
29/9	0524	12.62		12.74		12.76		12.87		12.95		
17/9	0202	43.36	45.33	43.48	45.51	43.51	45.58	43.60	45.73	43.68	45.98	41.99
17/9	0625	23.17	24.92	23.30	25.16	23.32	25.18	23.43	25.26	23.50	25.26	22.02
16/9	0626	48.86	51.72	48.90	51.57	48.85	51.61	48.88	51.53	49.02	51.45	46.94
16/9	0609	59.58	61.25	59.65	61.60	59.65	61.34	59.73	61.66	59.85	61.72	58.36
16/9	0629	26.37	27.20	26.48	27.22	26.55	27.29	26.60	27.53	26.69	27.61	25.93
20/1	2255	36.73	38.29	36.80	38.51	36.80	38.45	36.90	38.64	37.02	38.81	35.61
17/9	0454	50.51	52.21	50.59	52.36	50.57	52.33	50.67	52.56	50.80	52.74	49.30
24/9	0609	18.42	20.04	18.48	20.39	18.50	20.44	18.58	20.56	18.70	20.75	17.15
27/9	0603	6.60	8.24	6.66	8.53	6.67	8.53	6.76	8.75	6.88	8.90	5.34
25/9	0645	45.22	46.82	45.28	47.08	45.30	47.05	45.38	47.22	45.55	47.38	44.05
5/10	0239	28.23	29.83	28.27	29.95			28.32	29.93	28.24	29.80	27.09
6/10	0005	23.63	25.57	23.76	25.85			23.89	26.00	23.98	26.00	22.32
7/10	2329	15.45	16.97	15.58	17.18			15.61	17.17	15.82	17.26	14.50
5/10	0540	36.71	38.35	36.78	38.55			36.88	38.70	36.95	38.86	35.52
7/10	0424	48.73	50.44	48.81	50.66			48.90	50.80	49.02	50.87	47.53
12/10	0413	9.15	10.78	9.24	11.09			9.31	11.14	9.44	11.21	7.98
19/10	0549	29.96	31.22	30.03	31.23			30.13	31.36	30.25	31.64	29.16
16/10	0532	41.26	42.83	41.42	43.31			41.47	43.38	41.67	43.56	40.13
13/10	0239	2.89	4.56	3.00	4.74			3.05	4.99	3.20	5.14	1.70
25/10	0550	42.41	44.23	42.55	44.38			42.65	44.61	42.73	44.70	41.20
11/10	0527	6.64	8.50	6.76	8.85			6.88	9.00	6.97	9.08	5.32
12/10	0413	8.46	10.08	8.59	10.34			8.64	10.56	8.60	10.57	7.24
15/10	0540	25.22	26.96	25.27	27.02			25.36	27.25	25.48	27.42	24.00
12/10	0539	34.72	36.43	34.80	36.66			34.88	36.80	35.00	36.89	33.50

Table 1 (Cont'd)

Date	HR MIN U.T.	STN 1 Tp	STN 1 Ts	STN 2 Tp	STN 2 Ts	STN 3 Tp	STN 3 Ts	STN 4 Tp	STN 4 Ts	STN 5 Tp	STN 5 Ts	Average origin time
11/10	0315	41.72	43.55	41.79	43.70			41.86	43.72	42.00	44.08	40.44 s.
		.23	1.86	.25	2.00			.26	2.04	.26	2.13	58.96
21/10	0343	59.55	62.40	59.68	62.23			59.81	62.38	59.86	62.56	57.85
21/10	0437	52.69	53.76	52.81	54.06			52.99	54.22	53.10	54.63	51.97
18/10	0326	44.88	45.72	44.94	45.75			45.06	45.85	45.19	46.00	44.43
21/10	0627	39.03	40.70	39.15	40.86			39.27	41.05	39.36	41.20	37.92
29/10	0230	23.07	24.02	23.19	24.24			23.31	24.24	23.42	24.32	22.55
26/10	0155	16.06	18.02	16.17	18.21			16.29	18.50	16.39	18.57	14.69
30/10	0450	01.09	02.72	01.15	02.98			01.24	03.16	01.38	03.35	59.87
28/10	0531	20.32	22.00	20.40	22.23			20.48	22.38	20.61	22.58	19.10
27/10	0546	31.66	33.26	31.72	33.51			31.82	33.70	31.95	33.74	30.50
27/10	2121	42.05	43.70	42.13	43.85			42.22	44.00	42.33	44.18	40.90
25/10	0234	18.18	19.16	18.15	19.30			18.36	19.36	18.48	19.61	17.51
29/10	0516	43.58	45.27	43.69	45.54			43.73	45.58	43.87	45.86	42.39
25/10	0545	51.67	53.16	51.74	53.53			51.82	53.70	51.95	53.80	50.51
13/11	0037	36.44	38.18			36.51	38.32			36.72	38.66	35.46
15/11	0617	14.89	16.56			14.96	16.72			15.14	16.96	13.72
19/11	0557	12.89	14.72			13.08	14.95			13.24	15.23	11.68
18/11	0242	15.45	16.41			15.60	16.68			15.78	17.08	14.80
16/11	0059	36.29	37.55			36.37	37.73			36.58	37.92	35.45
24/11	0536	13.59	15.40			13.74	15.67			13.93	15.93	12.36
23/11	0346	07.30	09.24			07.44	09.47			07.62	09.93	5.92
25/11	0818	10.25	11.26			10.28	11.32			10.46	11.71	9.48
25/11	0512	05.07	06.86			05.33	07.07			05.41	07.35	3.94
25/11	0437	10.05	11.64			10.11	12.00			10.31	12.36	8.78
27/11	0818	36.36	37.42			36.41	37.45			36.64	37.84	35.66
26/11	0032	31.66	32.56			31.79	32.66			32.00	32.85	31.18
27/11	0812	03.82	05.08			03.86	05.14			04.07	05.32	2.99
30/11	0524	07.84	09.67			08.06	09.93					6.60
2/12	0330	25.38	26.44			25.54	26.72					24.64

TABLE 2

P-WAVE TRAVEL-TIMES AND DISTANCES FROM SELECTED EVENTS

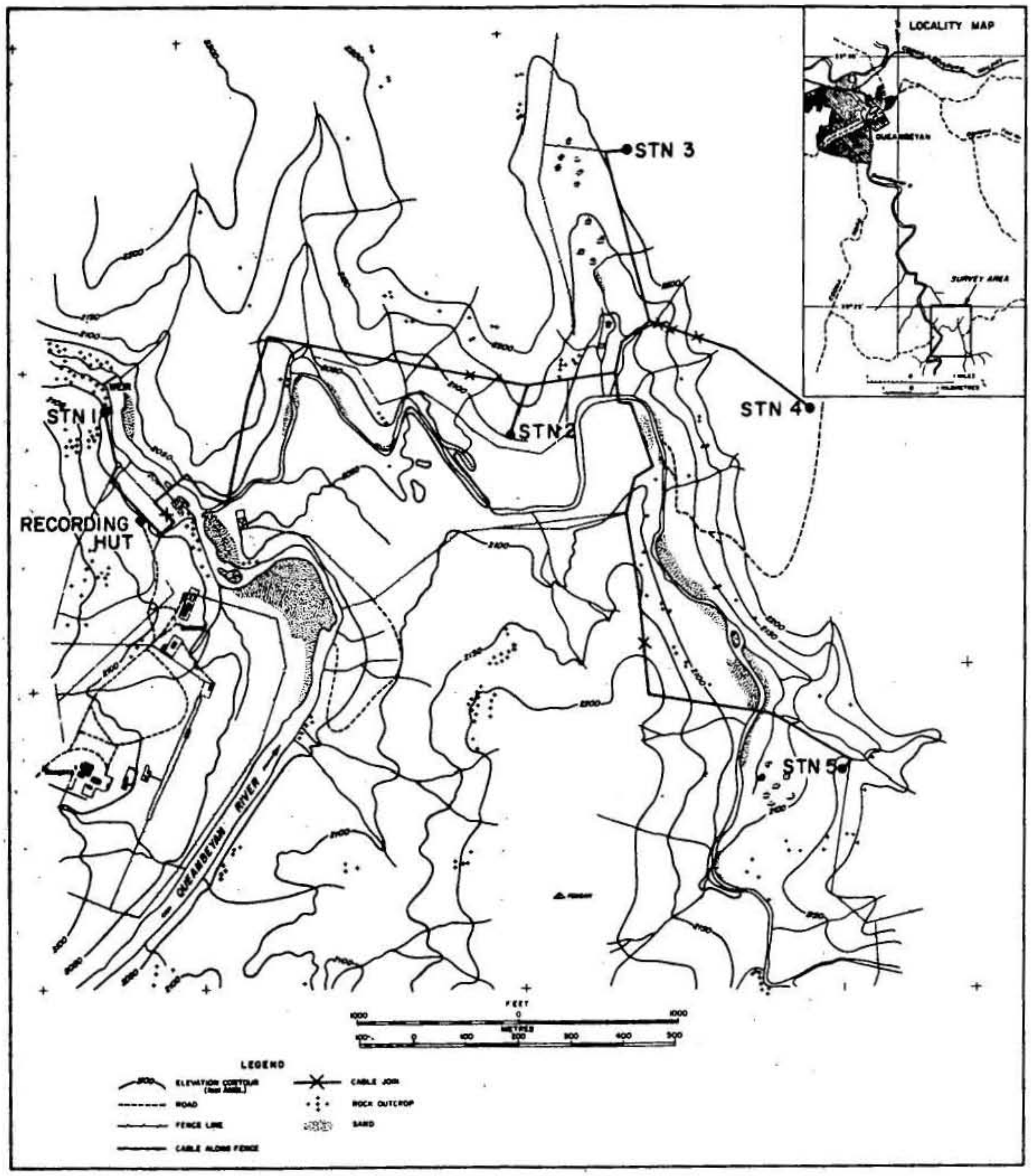
STN 1		STN 2		STN 3		STN 4		STN 5	
tt (s)	D (km)	tt (s)	D (km)	tt (s)	D (km)	tt (s)	D (km)	tt (s)	D (km)
1.73	11.25	1.22	7.93	1.22	7.93	1.32	8.58	1.42	9.23
1.06	6.89	1.16	7.54	1.14	7.41	1.24	8.06	1.36	8.84
1.27	8.26	1.35	8.78	1.34	8.71	1.46	9.49	1.57	10.21
1.08	7.02	1.15	7.48	1.15	7.48	1.25	8.13	1.36	8.84
1.15	7.48			1.21	7.87	1.31	8.52	1.44	9.36
0.71	4.62	0.81	5.27	0.82	5.33	0.93	6.05	1.02	6.63
1.17	7.61	1.33	8.65	1.33	8.65	1.44	9.36	1.51	9.82
1.14	7.41	1.20	7.8	1.20	7.8	1.30	8.45	1.40	9.10
1.12	7.28	1.19	7.74	1.19	7.74	1.29	8.39	1.39	9.04
1.22	7.93	1.30	8.45	1.29	8.39	1.39	9.04	1.47	9.56
1.37	8.91	1.49	9.69	1.52	8.88	1.61	10.47	1.69	10.99
1.15	7.48	1.28	8.32	1.30	8.45	1.41	9.17	1.48	9.62
1.92		1.96		1.91		1.94		2.08	
1.22	7.93	1.29	8.39	1.29	8.39	1.37	8.91	1.49	9.69
0.44	2.86	0.55	3.58	0.62	4.03	0.67	4.36	0.76	4.94
1.12	7.28	1.19	7.74	1.19	7.74	1.29	8.39	1.41	9.17
1.21	7.87	1.29	8.39	1.27	8.26	1.37	8.91	1.50	9.75
1.27	8.26	1.33	8.65	1.35	8.76	1.43	9.3	1.55	10.08
1.26	8.19	1.32	8.58	1.33	8.65	1.42	9.23	1.54	10.01
1.17	7.61	1.23	8.0	1.25	8.13	1.33	8.65	1.50	9.75
1.14	7.41	1.18	7.67			1.23	8.0	1.15	7.48
1.31	8.52	1.44	9.36			1.57	10.21	1.66	10.79
0.95	6.18	1.08	7.02			1.11	7.22	1.32	8.58
1.19	7.74	1.26	8.19			1.36	8.84	1.43	9.3
1.20	7.8	1.28	8.32			1.37	8.91	1.49	9.64
1.17	7.61	1.26	8.19			1.33	8.65	1.46	9.49
0.80	5.2	0.87	5.66			0.97	6.31	1.09	7.09
1.13	7.35	1.29	8.39			1.34	8.71	1.54	10.01
1.19	7.74	1.30	8.45			1.35	8.78	1.50	9.75
1.21	7.87	1.35	8.78			1.45	9.43	1.53	9.95
1.32	8.58	1.44	9.36			1.56	10.14	1.65	10.73
1.22	7.93	1.35	8.78			1.40	9.1	1.36	8.84
1.22	7.93	1.27	8.26			1.36	8.84	1.48	9.62
1.22	7.93	1.30	8.45			1.38	8.97	1.50	9.75
1.28	8.32	1.35	8.78			1.42	9.23	1.56	10.14

Table 2 (Cont'd)

STN 1		STN 2		STN 3		STN 4		STN 5	
tt (s)	D (km)	tt (s)	D (km)	tt (s)	D (km)	tt (s)	D (km)	tt (s)	D (km)
1.27	8.26	1.29	8.39			1.30	9.45	1.30	8.45
1.70	11.05	1.83	11.9			1.96	12.74	2.01	13.07
0.72	4.68	0.84	5.46			1.02	6.63	1.13	7.35
0.45	2.93	0.51	3.32			0.63	4.1	.76	4.94
1.11	7.22	1.23	8.00			1.35	8.78	1.44	9.36
0.52	3.38	0.64	4.16			0.76	4.94	0.87	5.66
1.37	8.91	1.48	9.62			1.60	10.4	1.70	11.05
1.22	7.93	1.28	8.32			1.37	8.91	1.51	9.82
1.16	7.54	1.22	7.93			1.32	8.58	1.45	9.43
1.15	7.48	1.23	8.00			1.32	8.58	1.43	9.3
0.67	4.36	0.64	4.16			0.85	5.53	0.97	6.31
1.19	7.74	1.30	8.45			1.34	8.71	1.48	9.62
1.16	7.54	1.23	8.00			1.31	8.52	1.44	9.36
0.98	6.37			1.05	6.83			1.26	8.19
1.17	7.61			1.24	8.06			1.42	9.23
1.21	7.87			1.40	9.1			1.56	10.14
0.65	4.23			0.80	5.2			0.98	6.37
0.84	5.46			0.92	5.98			1.13	7.35
1.23	8.0			1.38	8.97			1.57	10.21
1.38	8.97			1.52	9.88			1.70	11.05
0.77	5.01			0.80	5.2			0.98	6.37
1.13	7.35			1.39	9.04			1.47	9.56
1.27	8.26			1.33	8.65			1.53	9.95
0.70	4.55			0.75	4.88			0.98	6.37
0.48	3.12			0.61	3.97			0.82	5.33
0.84	5.4			0.87	5.66			1.08	7.02
1.24	8.06			1.54	10.01				
0.74	4.81			0.90	5.85				

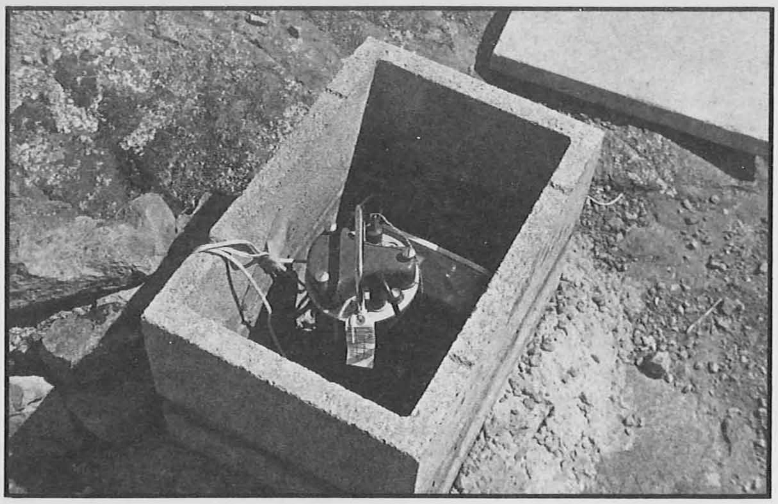
$tt = (t_p - \text{Av. To} - 1.2)$ seconds

see text for equation derivation

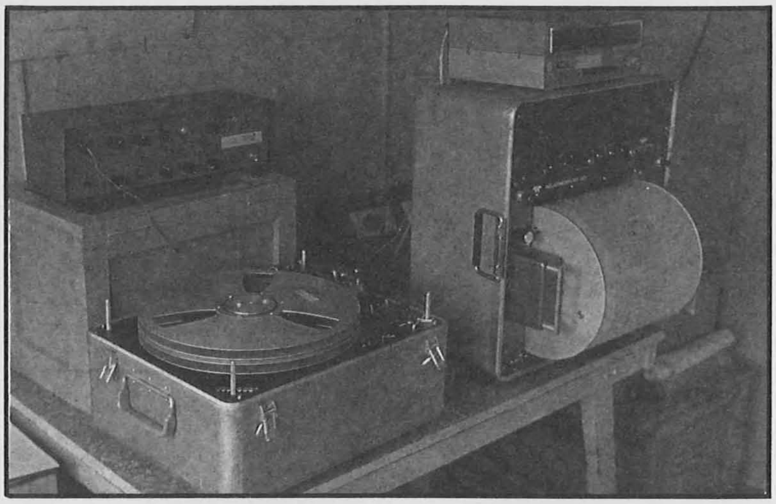


GOOGONG DAMSITE SEISMIC RECORDING STATIONS

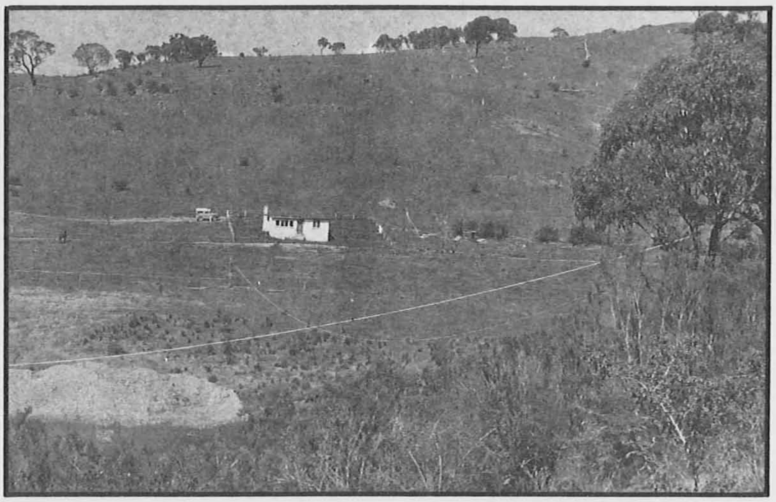
LOCALITY MAP



VAULT CONTAINING SEISMOMETER
AND VOLTAGE AMPLIFIER

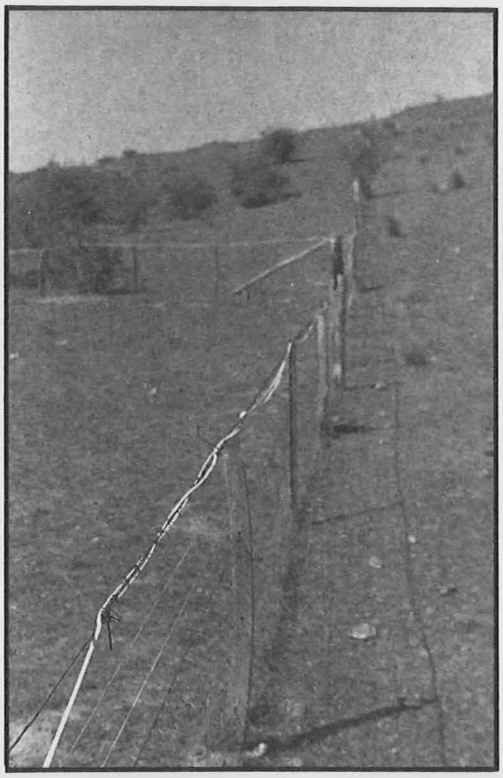


P.I. 5107 TAPE RECORDER
AND GEOTECH HELICORDER

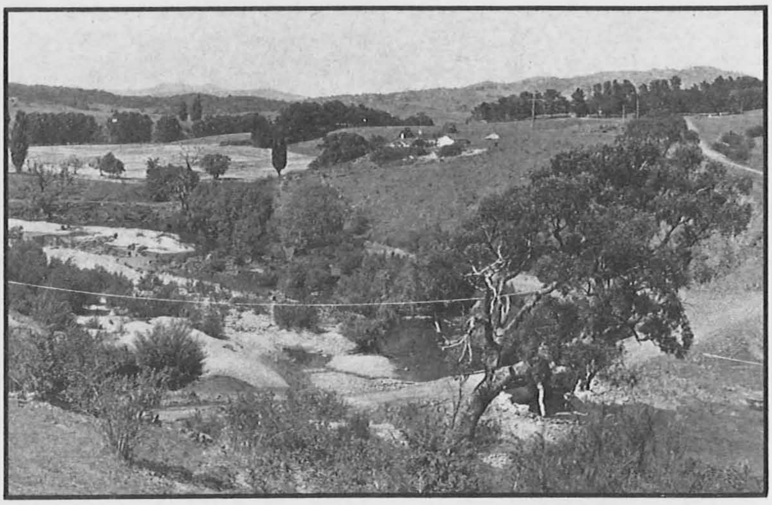


SIGNAL CABLE SPANNING RIVER

INSTRUMENTATION

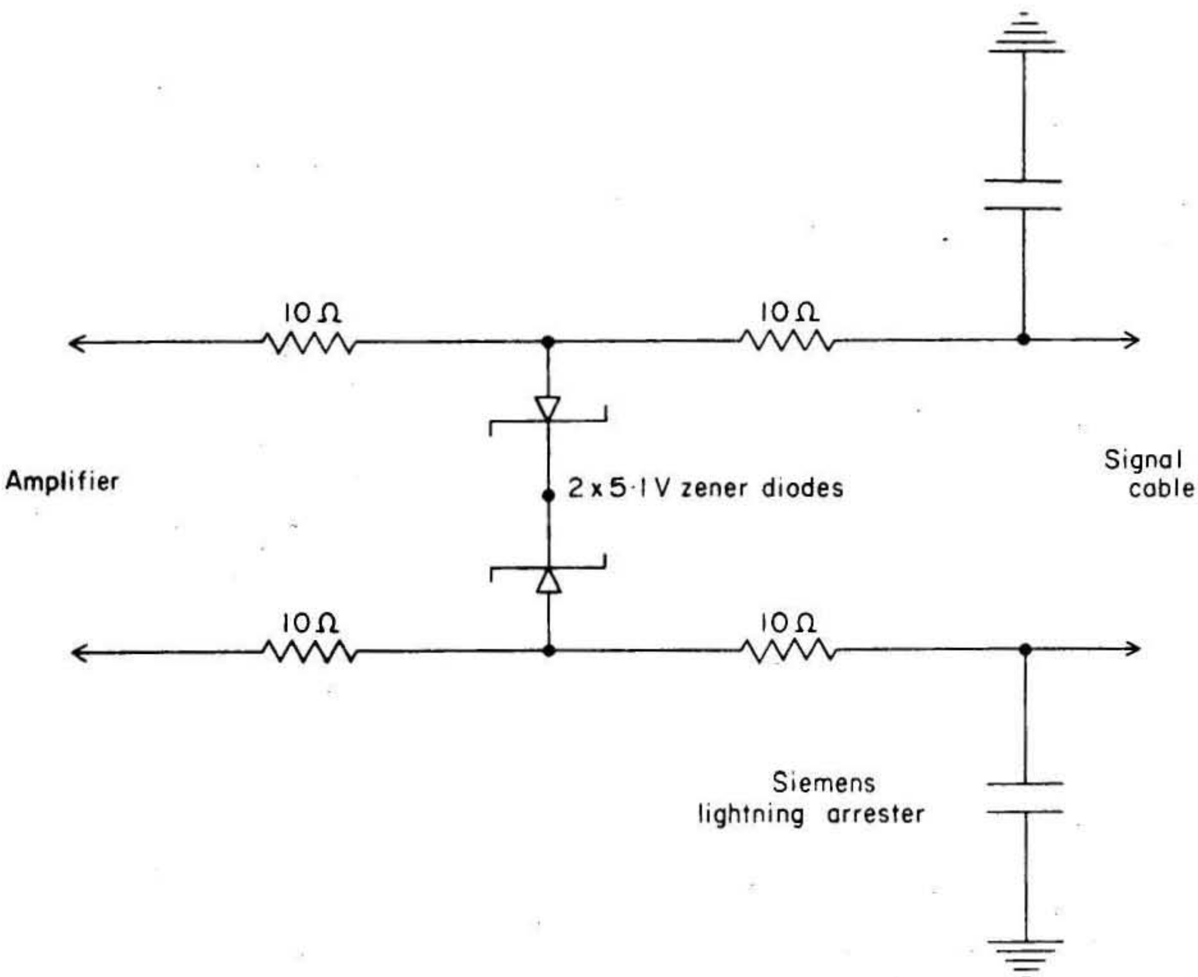


SIGNAL CABLE ALONG FENCING



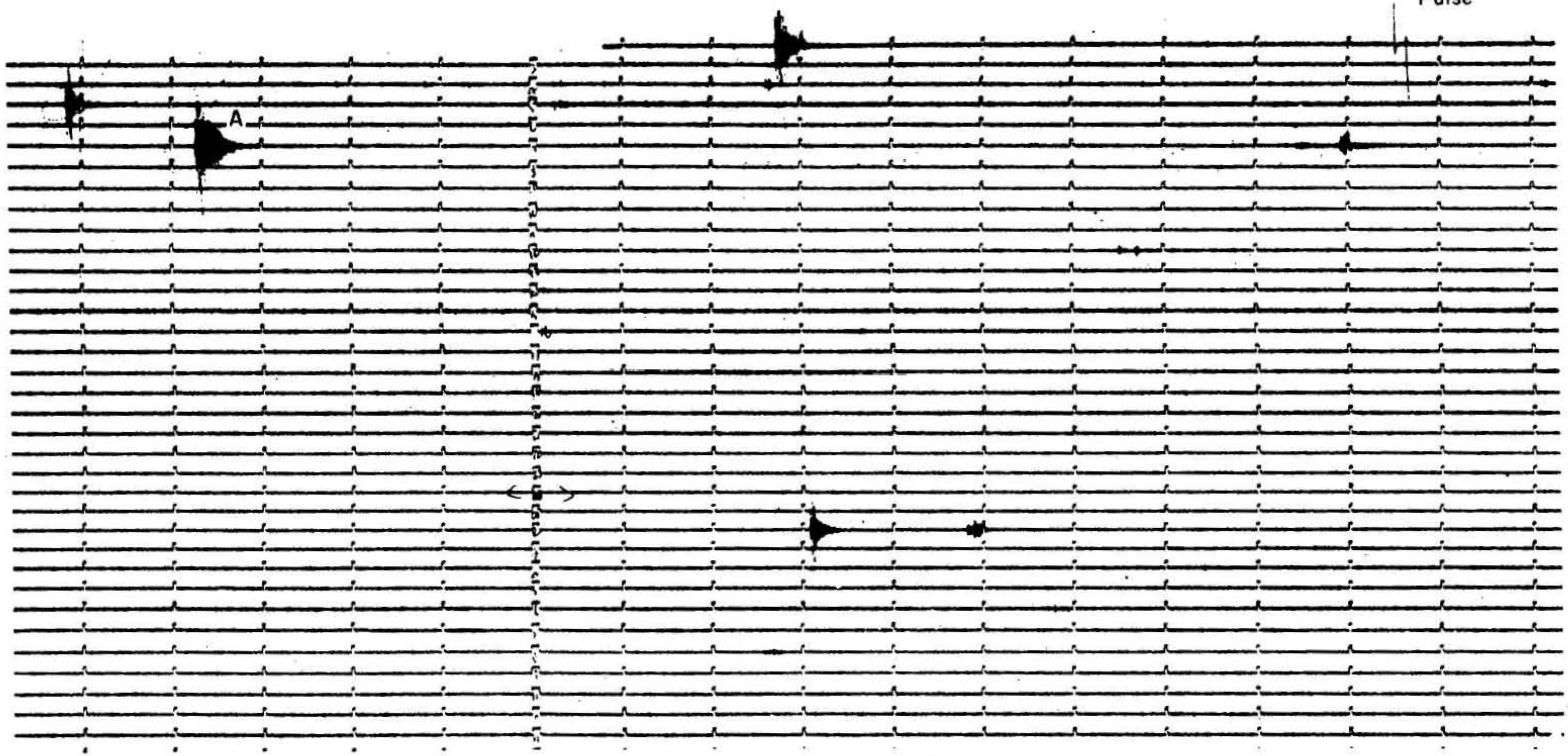
GENERAL VIEW OF STORAGE AREA

SIGNAL CABLE



LOW—VOLTAGE LIGHTNING PROTECTOR

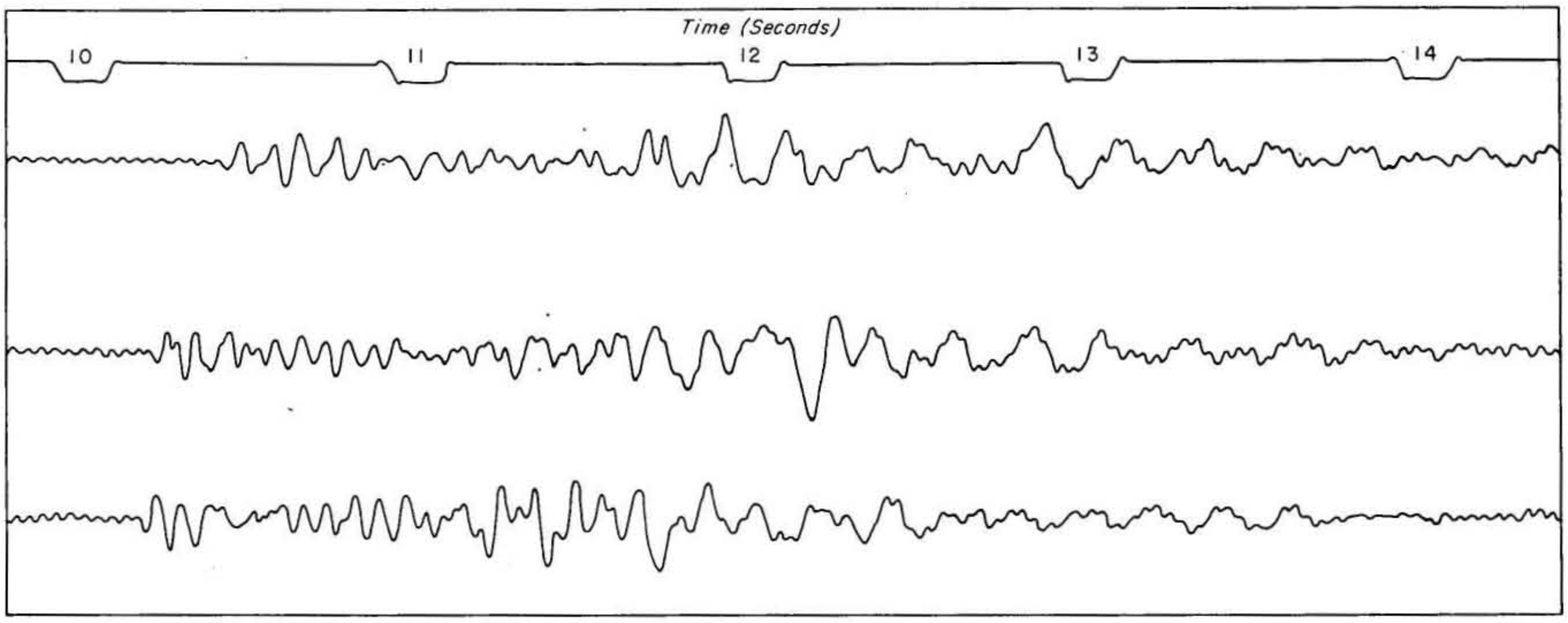
To Accompany Record No. 1972/75



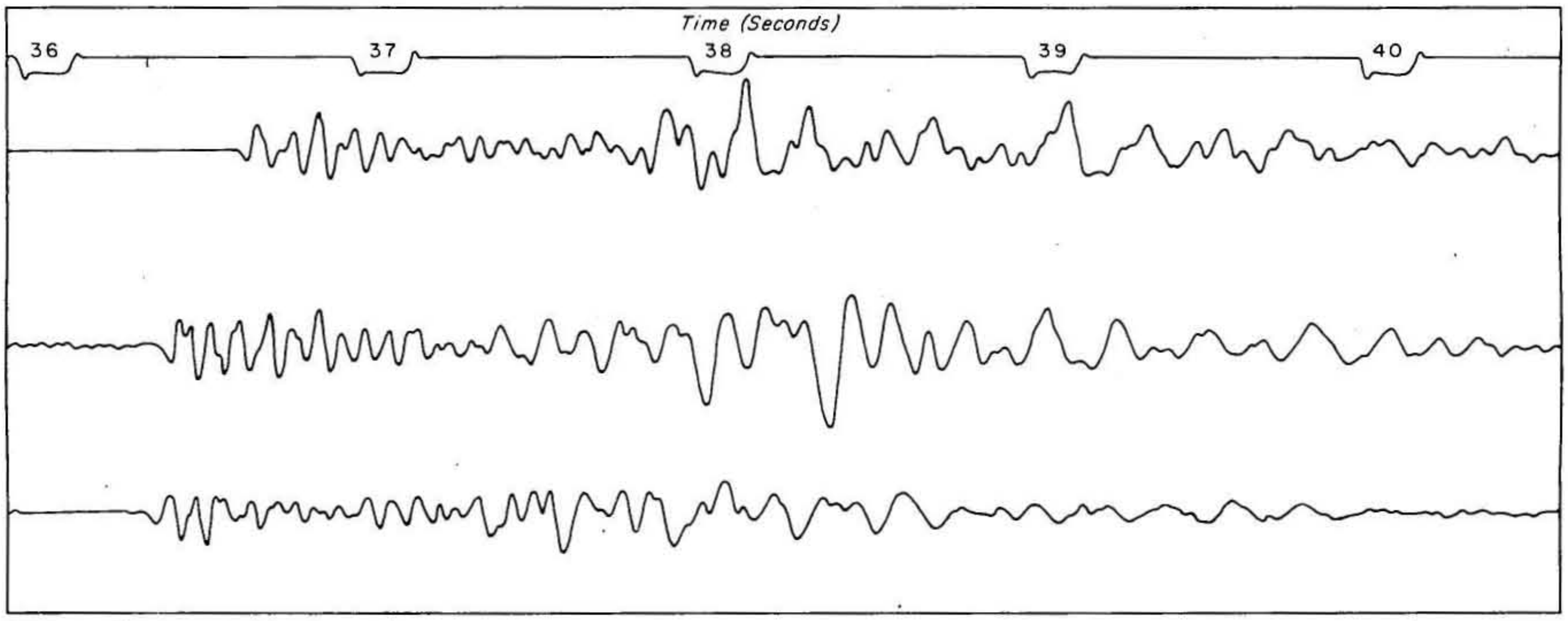
EXAMPLE OF HELICORDER RECORDS

155/B5-136 A

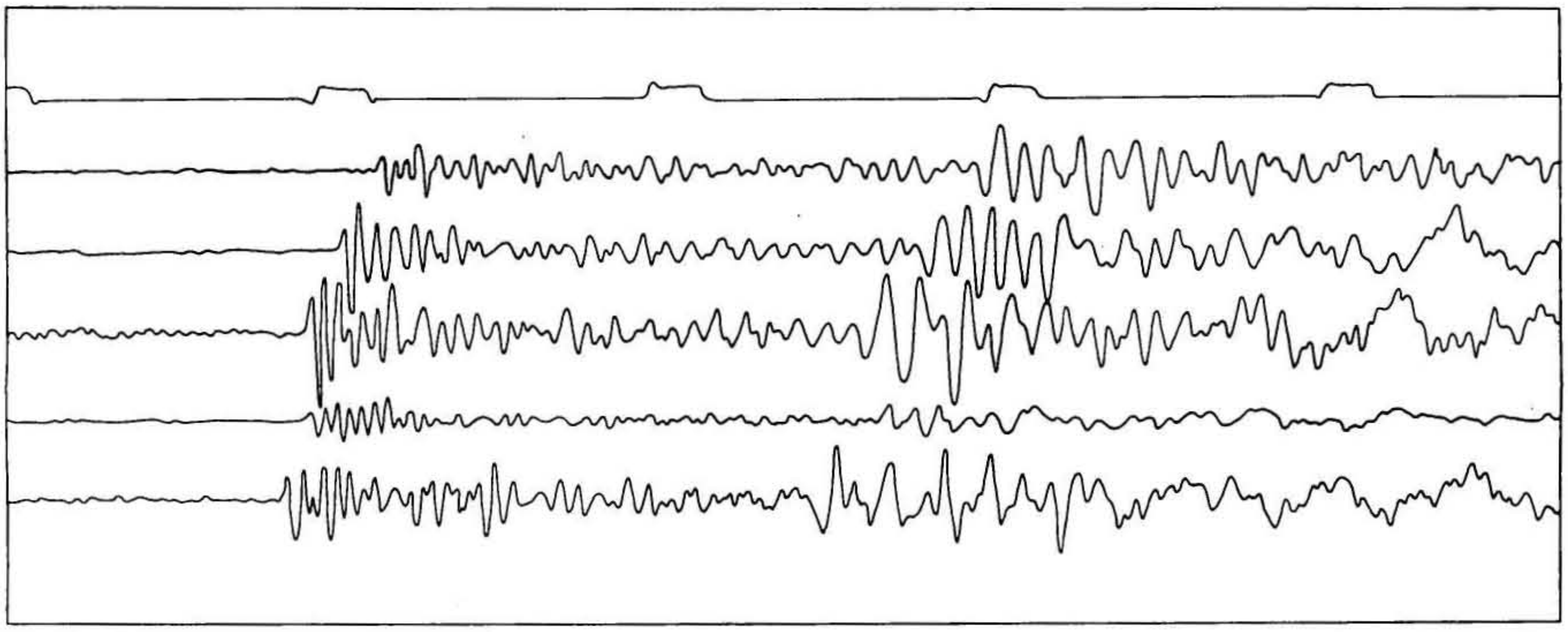
PLATE 5



Example 1 : EVENT A PLATE 7



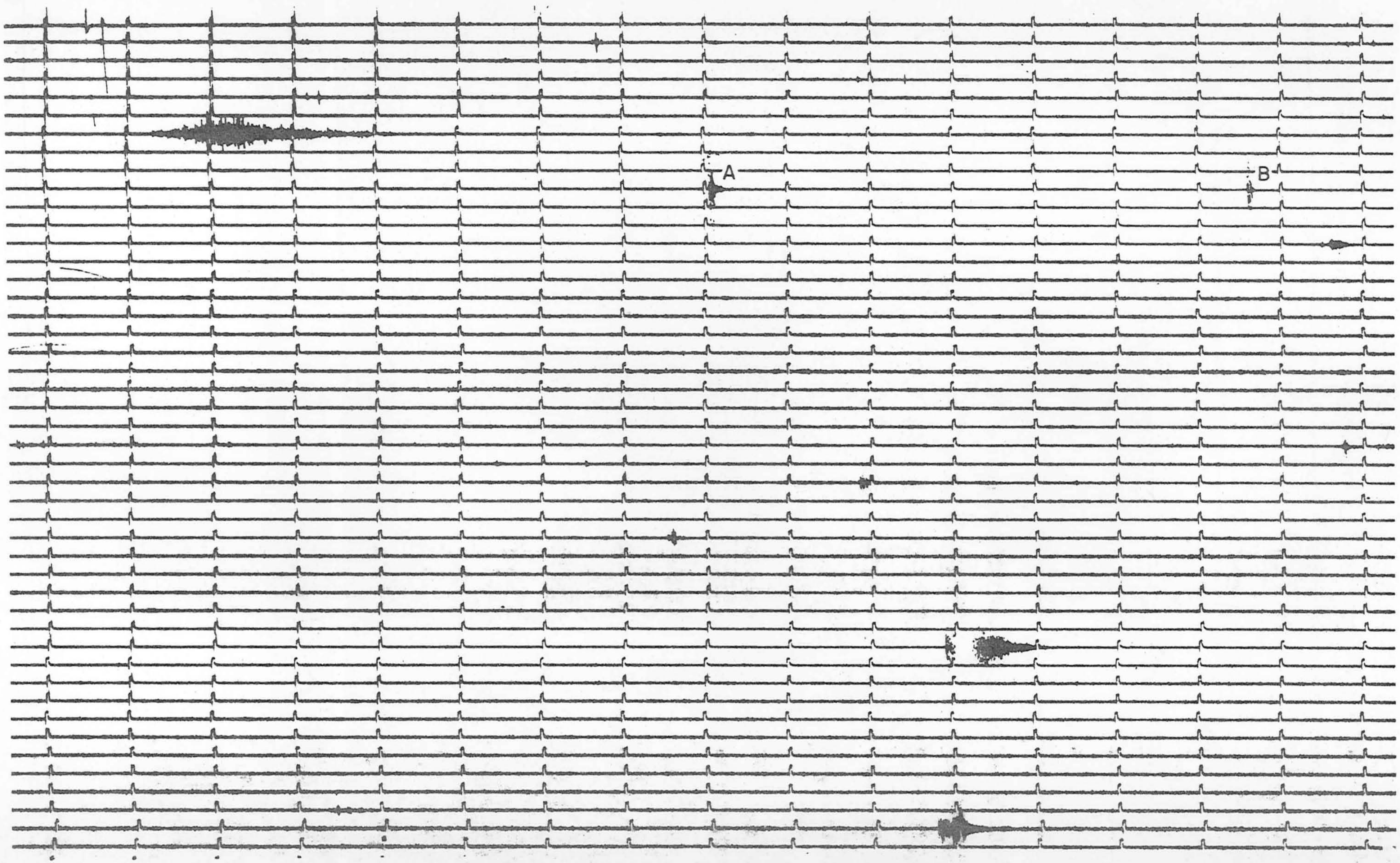
Example 2 : EVENT B PLATE 7



Example 3 : EVENT A PLATE 5

EXAMPLES OF SEISMIC PLAYBACK

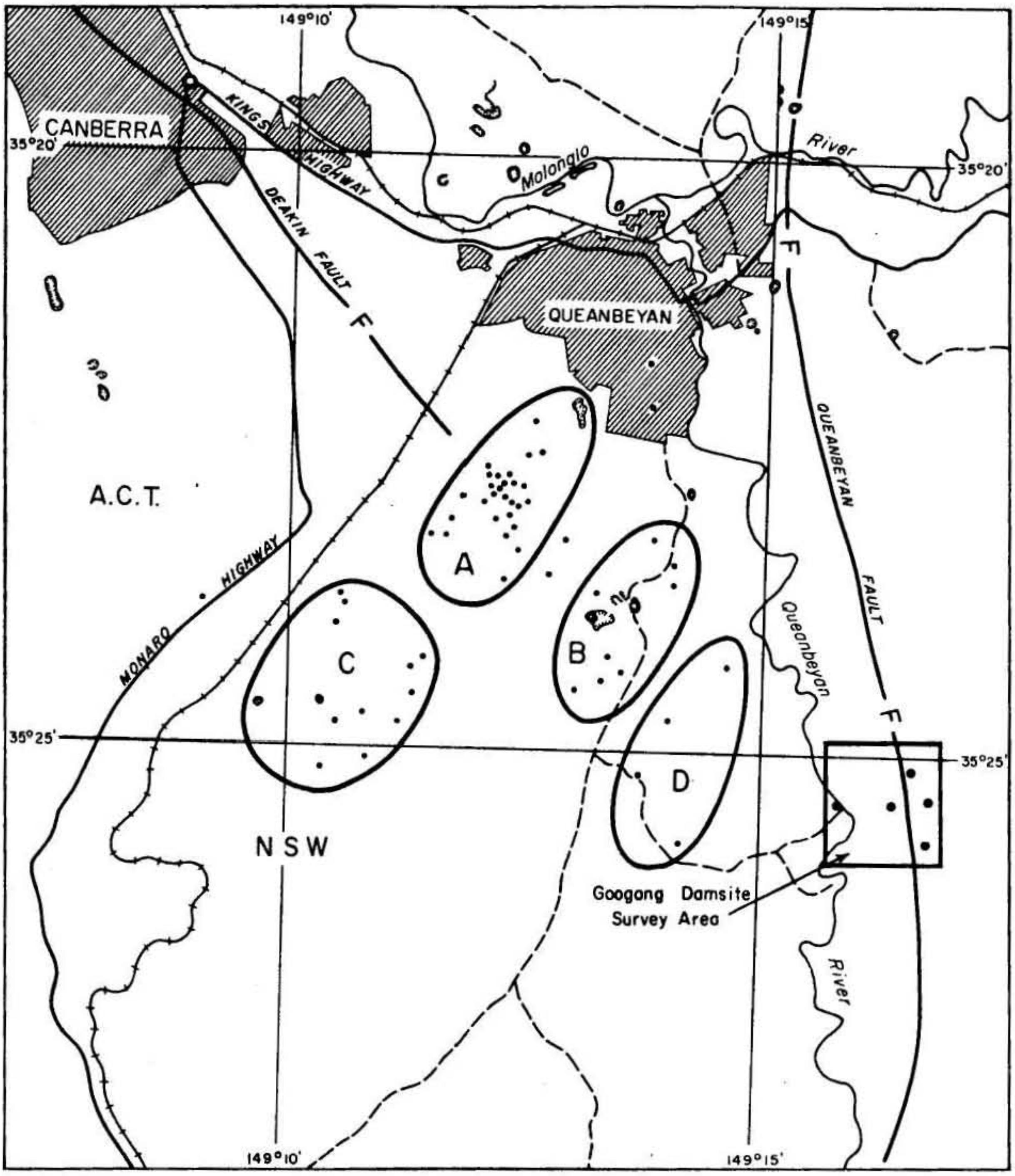
To Accompany Record No. 1972/75



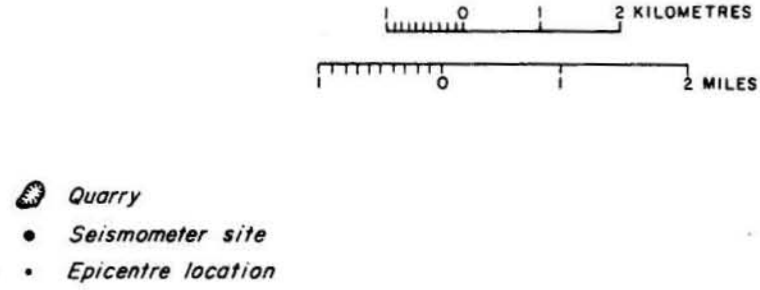
EXAMPLE OF HELICORDER RECORDS

PLATE 7

155/B5-135A



LOCATIONS OF SELECTED EVENTS RECORDED AT ARRAY



To Accompany Record No. 1972/75

I55/B5-140A

MAGNITUDE CALLIBRATION

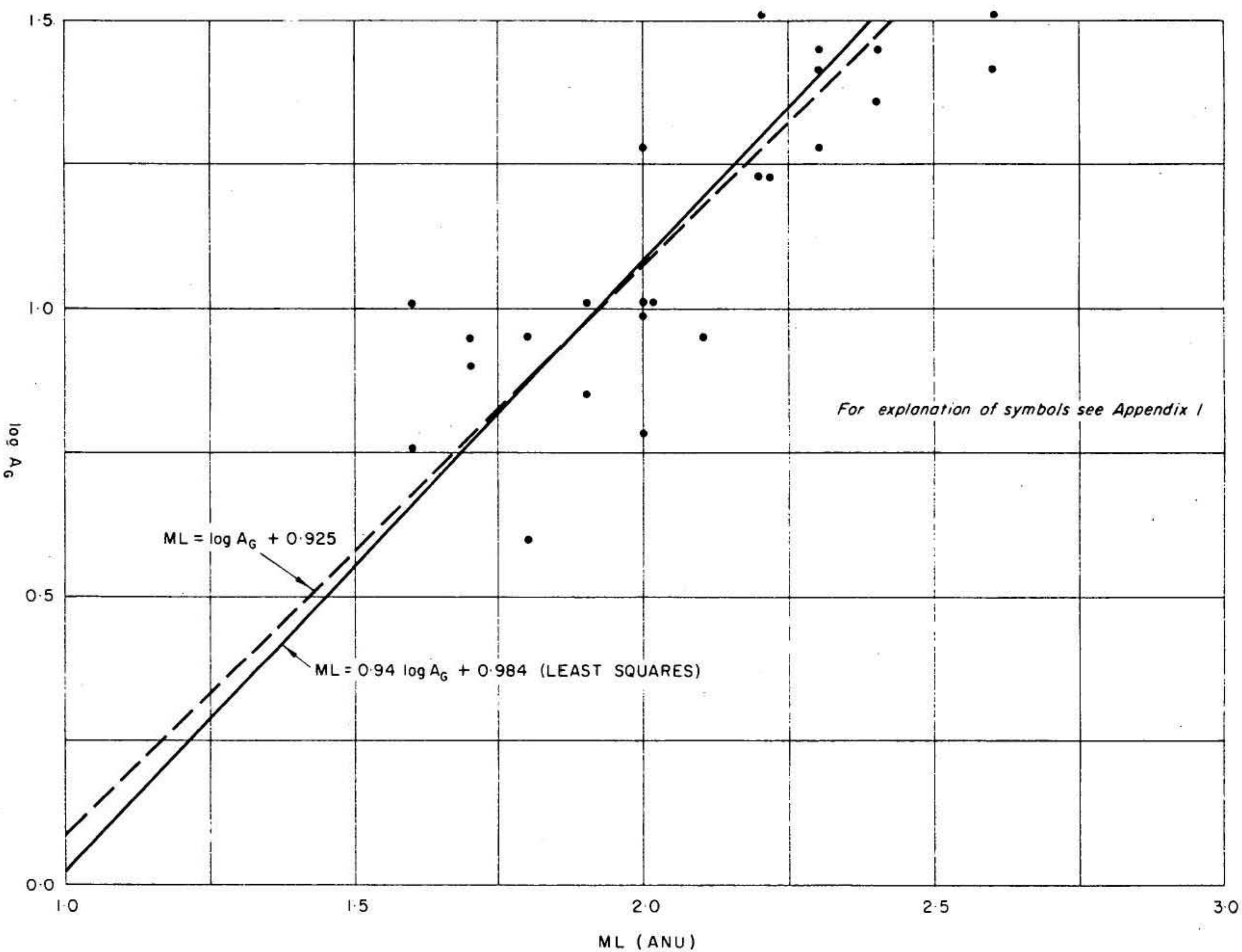


PLATE 9