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DEPARTMENT OF
MINERALS AND ENERGY

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

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SOME STRONG-MOTION SEISMIC RESULTS FROM PAPUA NEW GUINEA 1967-1972

by

D. Denham, G.R. Small and I.B. Everingham

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SUMMARY

The Australian Bureau of Mineral Resources maintains, in Canberra, a strong-motion data centre for the collection, storage, distribution, and analysis of accelerograms from Australia and Papua New Guinea. The processing facilities and analysing procedures at the centre are described and some of the results are presented from the accelerograms obtained from Papua New Guinea.

In the period 1967-1972, 16 accelerographs were installed in Papua New Guinea and 44 usable accelerograms have been obtained from 40 earthquakes. The highest recorded ground acceleration was only about 190 cm/s^2 but the duration of shaking at levels greater than 40 cm/s^2 exceeded 90 s for several earthquakes.

The most prolific sites have been at Yonki on the New Guinea mainland, and at Panguna on Bougainville Island. At Yonki the accelerograph has been triggered by 20 earthquakes, including the magnitude 7.0 (MS) Madang earthquake of 31 October 1970 and its largest aftershock. The main Madang shock took place about 165 km from the accelerograph, which recorded a maximum acceleration of 93 cm/s^2 and maximum velocity of 4 cm/s. At Panguna, accelerograms have been obtained from five earthquakes including the magnitude 8.0 (MS) Solomon Sea earthquakes of 14 and 26 July 1971. These occurred at 210 and 300 km from the accelerograph and produced maximum accelerations of 124 and 59 cm/s^2 and velocities of 13.0 and 5.4 cm/s respectively.

The ground response at Yonki and Panguna is shown to be strongly influenced by the local geological conditions, and although empirical relations between ground movement, earthquake magnitude, and distance can be derived, the errors in the constants of the equations preclude accurate predictions of ground motion at these sites.

1. INTRODUCTION

Although the high level of earthquake activity in the New Guinea region has been known for many years it is only recently, with the improvement in the worldwide coverage of seismographs and the installation of several regional stations, that the distribution of earthquakes here has become clear (Ref.1). In the New Guinea region the interaction of the main Pacific and Indian/ Australian Plates does not take place along a single boundary. Instead there are several small rigid plates or subplates, all moving relatively to the others (Ref.2). Plate 1 indicates the distribution of earthquakes in the region for the period 1958-1970, the probable plate boundaries, and the locations of the accelerographs.

The main Pacific Plate is numbered(1), the main Indian/ Australian Plate is numbered(2), and the others are termed the North Bismarck Sea Plate (3), the South Bismark Sea Plate (4), the Solomon Sea Plate (5), and the possible Woodlark Basin Plate (6?). From the earthquake risk aspect there are four very active plate boundaries where large shallow earthquakes occur frequently. One of the most active of these boundaries is the New Britain Arc, which contains a typical Benioff zone that dips to the north beneath the island of New Britain. This zone forms the boundary between the South Bismarck Sea Plate and the Solomon Sea Plate, and the rate of underthrusting of the latter is about 9 cm/yr (Ref.3). Large shallow earthquakes frequently occur near the south coast of New Britain. The Solomon Island Arc represents the boundary between the Solomon Sea Plate and the main Pacific Plate. The Benioff zone associated with this arc dips very steeply, and very few earthquakes have been reported from beneath Bougainville Island. The rate of underthrusting is about 10 cm/yr (Ref.3) and the proximity of this zone to Bougainville Island, New Ireland, and east New Britain results in a very high earthquake risk in these regions.

The third important zone of earthquakes is represented by the remarkable line of shallow earthquakes that extends across the Bismarck Sea at about latitude 3°S. This separates the North and South Bismarck Sea Plates and probably represents a large left-lateral strike slip fault (Ref.2). Fortunately most of the earthquakes in this zone occur beneath the sea, and the seismic risk from it is important only where the zone joins the New Guinea mainland near 144°E.

Twelve permanent seismographs were in operation during 1972 in Papua New Guinea. This coverage enables epicentres of most earthquakes over a magnitude of 5 to be located with an accuracy of about 0.1 degree. The strong-motion coverage of the region consists of a network of sixteen accelerographs made up of fourteen M02s and two SMA1s. Most accelerographs were installed to give results for definite development projects. The instruments at Panguna, Frieda River, and the Star Mountains were all sited to assist mining companies in determining earthquake risk factors in and around mining projects. At Ramu and Musa, accelerographs were installed to record ground motion in the vicinity of projected hydro-electric schemes. At each of the previous five sites one accelerograph was placed on soft rock and one on hard rock.

All the other strong-motion instruments were installed to give general background information at or near major centres of population except two at Lae, which were sited to determine the response of a water tower. This paper describes the results from the two most prolific accelerographs, on the soft-rock sites at Yonki and Panguna.

2. METHODS OF ANALYSIS

At the time of writing, 44 usable accelerograms have been obtained from the M02 accelerographs. The original 35-mm film records are copied and enlarged photographically by a factor of about 5. The accelerograms are then digitized at 0.02-s intervals on a scaling table. Digitized ordinates are obtained from a shaft-position encoding disc fitted to the Y-drive of the scaler. The output from the scaler is coupled to a paper-tape punch. The 4096-position encoder allows a resolution of about one-thirteenth of a millimetre, and the accuracy of the system is probably about 0.1 mm. At a magnification of 5, 0.1 mm corresponds to an acceleration of about 1 cm/s^2 on a typical M02 horizontal trace. The limiting factor is usually set by the trace thickness, which can be up to 0.5 mm on the enlarged film.

The methods for analysing the accelerograms are based on those developed by Nigam & Jennings (Refs.4, 5). The ever-present low-frequency noise is tackled by passing the digitized data through a bandpass filter which cuts at 0.2 and 15 Hz. The standard parabolic correction is applied before and after the filtering procedure. On some of the records the baseline was missing and the edge of the film was used instead. When this occurred the analysis of the records would have been impossible without filtering.

3. RESULTS FROM YONKI AND PANGUNA

At Yonki the soft-rock accelerograph, situated on about 50 m of recent alluvium, has been triggered by 20 earthquakes. Its companion on hard rock, less than 500 m away, has never been triggered. Table 1 contains details of the earthquakes that triggered the soft-rock instrument and also the main results obtained. From the 20 triggerings it was possible to calculate the maximum acceleration on 14 accelerograms. The value obtained from the earthquake of 16 September 1968 is probably an under-estimate of the maximum ground motion because the accelerograph was triggered by the S-wave and the maximum acceleration was missed. Estimates of maximum velocity were obtained from 12 records and power spectral analyses were carried out on 10. Plate 2 shows the location of the Yonki instrument and the earthquakes that triggered it. Plates 4 and 5 contain plots of the accelerations and velocities recorded.

The points show considerable scatter and some anomalous values; in particular the results from the October 1970 Madang earthquake and its aftershock on 12 November 1970 give consistently smaller accelerations and velocities than other earthquakes of similar magnitudes and distances from Yonki. Using the standard relation:

$$Y = a\ c^{bM} R^{c} \qquad (1)$$

where Y is the maximum acceleration or velocity
M is the earthquake magnitude
R is the distance
a, b, c are constants

least-squares analyses for Yonki lead to the following equations:

$$\log Y_a = 2.26 + (0.40 \pm 0.20)\ ML - (1.41 \pm 0.87) \log R \qquad (2)$$

$$\log Y_v = -1.16 + (0.29 \pm 0.16)\ ML - (0.09 \pm 0.12) \log R \qquad (3)$$

Where Y_a and Y_v are in cm/s^2 and cm/s respectively, ML is the Richter magnitude of the earthquake, and R the distance is km. The standard errors of the regression coefficients are very large and preclude the use of a simple relation like formula (1) to describe the Yonki results. The spectral analyses of Yonki accelerations exhibit some scatter, but on all the 10 accelerograms analysed, most of the energy is contained in a 2-8 Hz band and 7 of these have the main peak near 4.5 Hz. Plate 6 shows the results from the 1970 Madang earthquake, using 90 s of data sampled at 0.02-s intervals. The spectral shape is as typical as any of the spectra obtained; it has a peak near 4.5 Hz and most of the energy lies in the 3-6 Hz frequency band. Plate 8 shows the corrected accelerations and velocities obtained from the earthquake of 14 February 1971, which resulted in the highest recorded acceleration and velocity at Yonki.

The accelerograph at Panguna was installed on unconsolidated volcanic ash. Five accelerograms have been obtained from known earthquakes. Plate 3 shows the locations of the earthquakes and Table 2 lists the results obtained. The largest values of ground motion were reported from the magnitude 8 earthquake of 14 July 1971. This event took place about 210 km from the accelerograph and produced maximum accelerations and velocities of 124 cm/s^2 and 13 cm/s respectively. There are not enough data to attempt a multiple regression, but if the Panguna and Yonki observations are combined the following equations result:

$$\log Y_a = 2.91 + (0.32 \pm 0.11)\, ML - (1.45 \pm 0.57) \log R \qquad (4)$$

$$\log Y_v = -0.55 + (0.22 \pm 0.08)\, ML - (0.14 \pm 0.12) \log R \qquad (5)$$

The validity of the combination procedure may be questioned because of the differences in the geological foundation at the two sites, but the regression coefficients have much smaller standard errors when the Yonki and Panguna data are combined.

The power spectra obtained from the Panguna accelerograms have very similar shapes with a peak at 1.8 Hz and do not show the variability observed at Yonki. Plate 7 shows the spectra obtained from the earthquake of 14 July 1971 using about 90 s of record in the analysis. The largest ground motion was recorded on the horizontal component, shaking in the NE-SW direction. Plate 8 shows part of this accelerogram and the accelerations and velocities obtained. One remarkable feature of the earthquake of 14 July 1971 was the duration of the shaking. At the end of 90 s ground accelerations of about 50 cm/s^2 were still being recorded on the NE-SE horizontal component, making the accelerogram very similar to that obtained in Mexico City in July 1964 (Ref.6).

Although good empirical relations of ground motion to magnitude and distance cannot be obtained from the Yonki and Panguna results, the dependence of maximum acceleration and velocity on the observed Modified Mercalli intensity (I) is very strong, and least-squares fits to the data in Tables 1 and 2 give the following results.

Panguna

$$\log Y_a = (-0.2 \pm 0.3) + (0.4 \pm 0.1)I$$

$$\log Y_v = (-1.6 \pm 0.2) + (0.4 \pm 0.1)I$$

Yonki

$$\log Y_a = (0.0 \pm 0.3) + (0.4 \pm 0.1)I$$

$$\log Y_v = (-0.6 \pm 0.2) + (0.2 \pm 0.1)I$$

These relations show that the acceleration/intensity relation are similar at both sites but the velocity/intensity relationsare different.

4. CONCLUSIONS

The strong-motion results from Papua New Guinea show that in a region of high earthquake activity it is possible to obtain many accelerograph triggerings if the instruments are situated on recent unconsolidated rock. On hard rock no triggerings have been obtained; this implies that at Panguna and Yonki there is a large amplification factor between the hard and soft rock sites because the M02 accelerographs should trigger at vertical accelerations of about 10 cm/s^2.

Formal relations between ground motion, magnitude, and distance must be treated with extreme caution because of the weak statistical relations between these parameters. All estimates of expected accelerations and velocities will have large standard errors, and from the available evidence ground movement cannot be predicted accurately.

5. ACKNOWLEDGEMENTS

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TABLE 1

Results from accelerograph on soft-rock site, Yonki (6.24°S, 145.98°E)

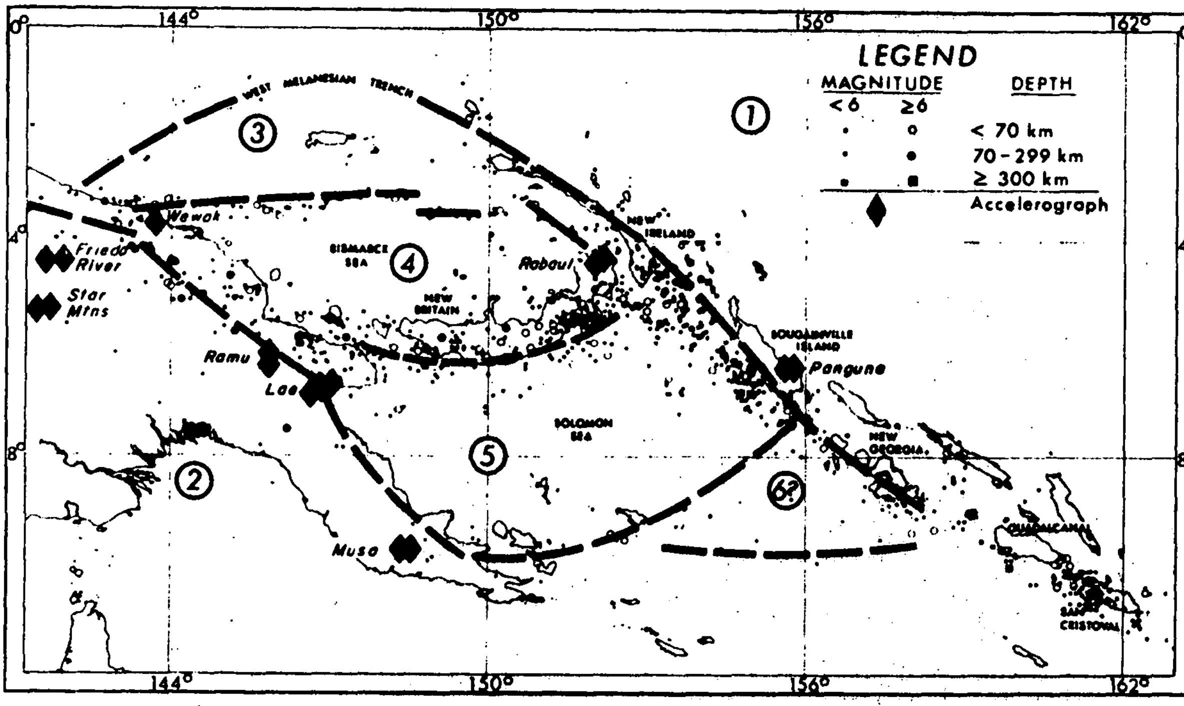
Date	Epicentre Lat S	Long E	Distance km	Magnitude MB	ML	MS	Max acc cm/s^2	Max vel cm/s	MM int
14 NOV 1967	5.43	147.07	253	5.8	6.4	6.0	54	2.7	V
28 APR 1968	5.53	146.32	097	5.6	5.2	5.6	27	1.3	?
11 MAY 1968	6.41	147.28	165	5.5	6.0	5.8	Film	U/S	V
03 JUN 1968	5.45	146.95	237	5.6	6.2	5.9	32	2.1	IV
17 JUN 1968	6.27	146.59	131	5.1	6.0	5.3	38	2.3	V
16 SEP 1968	6.07	148.68	305	6.2	6.7	6.3	09	-	III-IV
07 JAN 1969	6.19	146.44	112	5.3	-	5.6	14	1.9	III-IV
10 MAR 1969	5.59	147.21	259	5.8	6.8	6.4	40	2.7	V
08 MAY 1969	5.57	146.20	111	5.1	5.7	5.4	Film	U/S	?
14 JUN 1969	5.56	145.52	148	5.2	6.1	5.5	Film	U/S	?
24 JUN 1969	5.82	146.77	152	5.6	6.0	6.0	63	No timing	V
13 MAY 1970	5.89	146.75	152	5.2	5.6	5.4	33	1.5	?
31 OCT 1970	4.93	145.07	162	6.0	7.1	7.0	93	4.0	V-VI
12 NOV 1970	5.05	145.06	168	5.9	6.6	6.6	25	2.6	III-IV
12 FEB 1971	6.25	146.48	128	5.7	6.1	6.0	187	10.2	VI
13 MAR 1971	5.72	145.37	149	6.3	6.2	6.5	79	3.4	V
10 JUL 1971	5.86	144.44	189	5.4	5.9	5.5	10	1.2	III
16/7-17/8 1971 EARTHQUAKE UNKNOWN									
25 SEP 1971	6.54	146.58	138	6.3	6.7	6.9	Film	U/S	V-VI
18 JAN 1971	4.78	145.04	166	5.7	6.6	6.6	Film	U/S	?

TABLE 2

Results from accelerograph on soft-rock site, Panguna (6.32°S, 155.48°E)

Date	Epicentre Lat S	Long E	Distance km	Magnitude MB	ML	MS	Mac acc cm/s^2	Mac vel cm/s	MM int
07 SEP 1969	6.56	155.77	178	5.3	5.6	5.6	59	4.3	V
16 NOV 1969	6.54	155.02	080	5.2	5.2	5.2	39	3.1	V-VI
28 MAR 1970	6.26	154.63	114	5.9	6.1	5.9	123	7.5	VI
14 JUL 1971	5.47	153.88	207	6.3	8.0	8.0	124	13.0	VI-VII
26 JUL 1971	4.94	153.17	302	6.3	8.0	8.0	59	5.4	V-VI

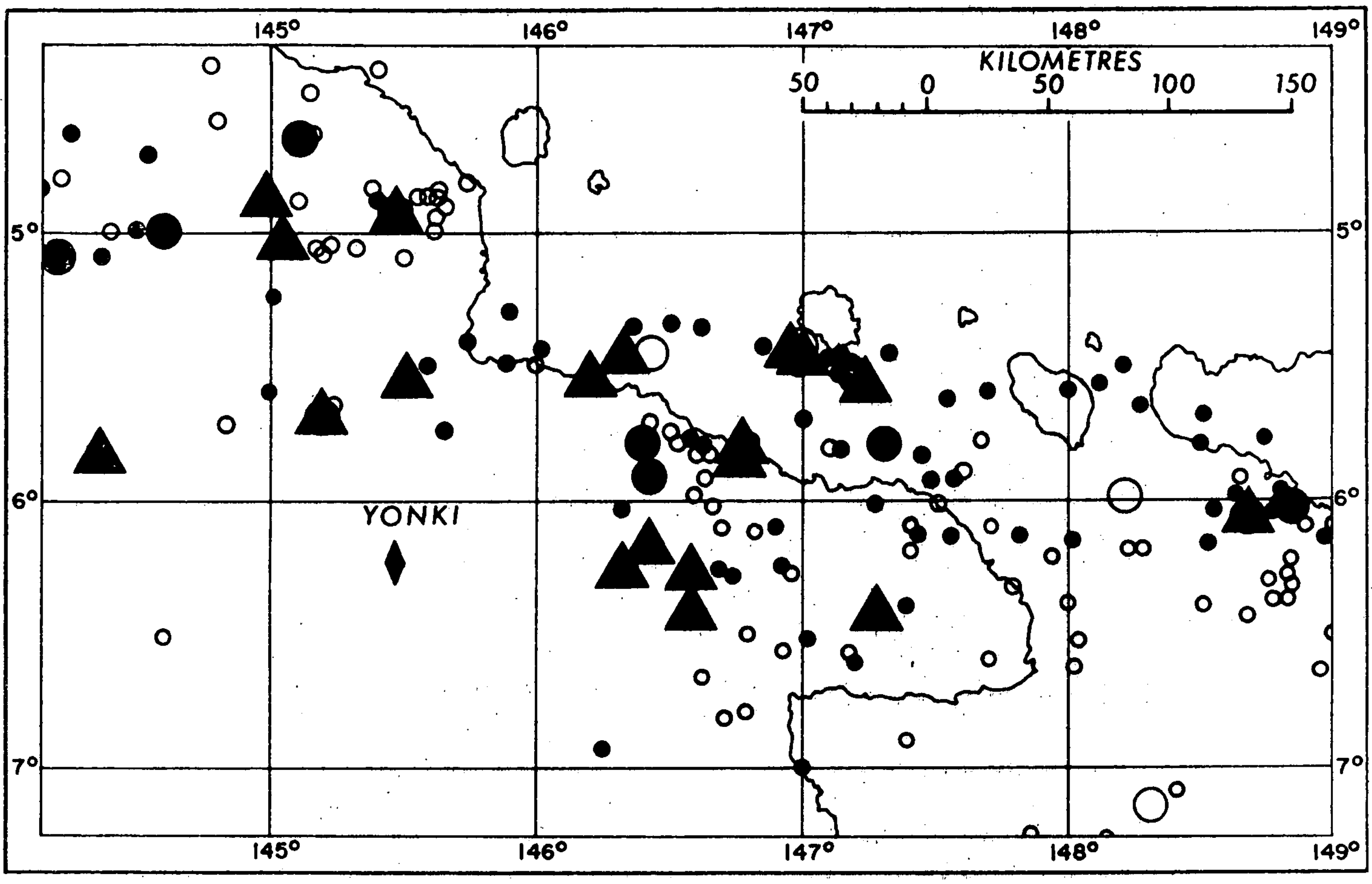
PLATE I



Based on PNG/B9-144-1A

DISTRIBUTION OF EARTHQUAKES, PLATES AND ACCELEROGRAPHS - PLATE NOMENCLATURE IN TEXT

To accompany record No. 1973/13 PNG/B9-144-2A

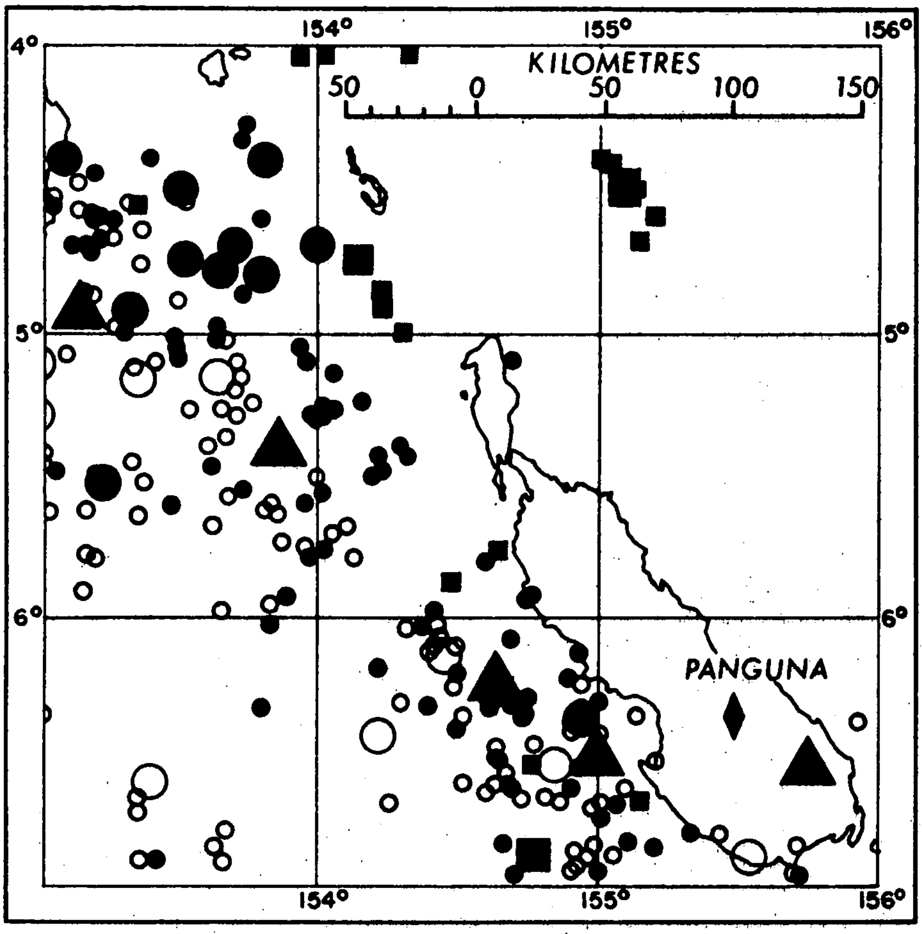


EARTHQUAKES ▲ WHICH TRIGGERED YONKI ACCELEROGRAPH

To accompany record No. 1973-13

PNG/B9-141-5A

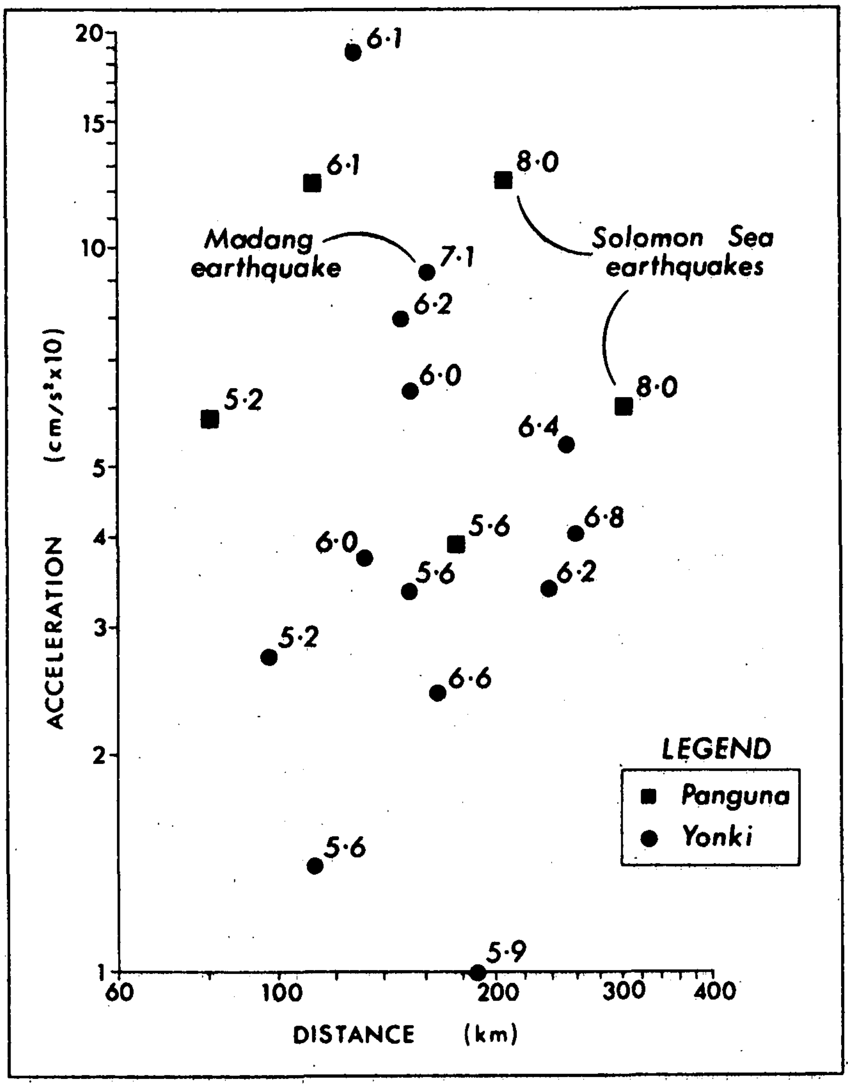
PLATE 3



Based on PNG/B9-141

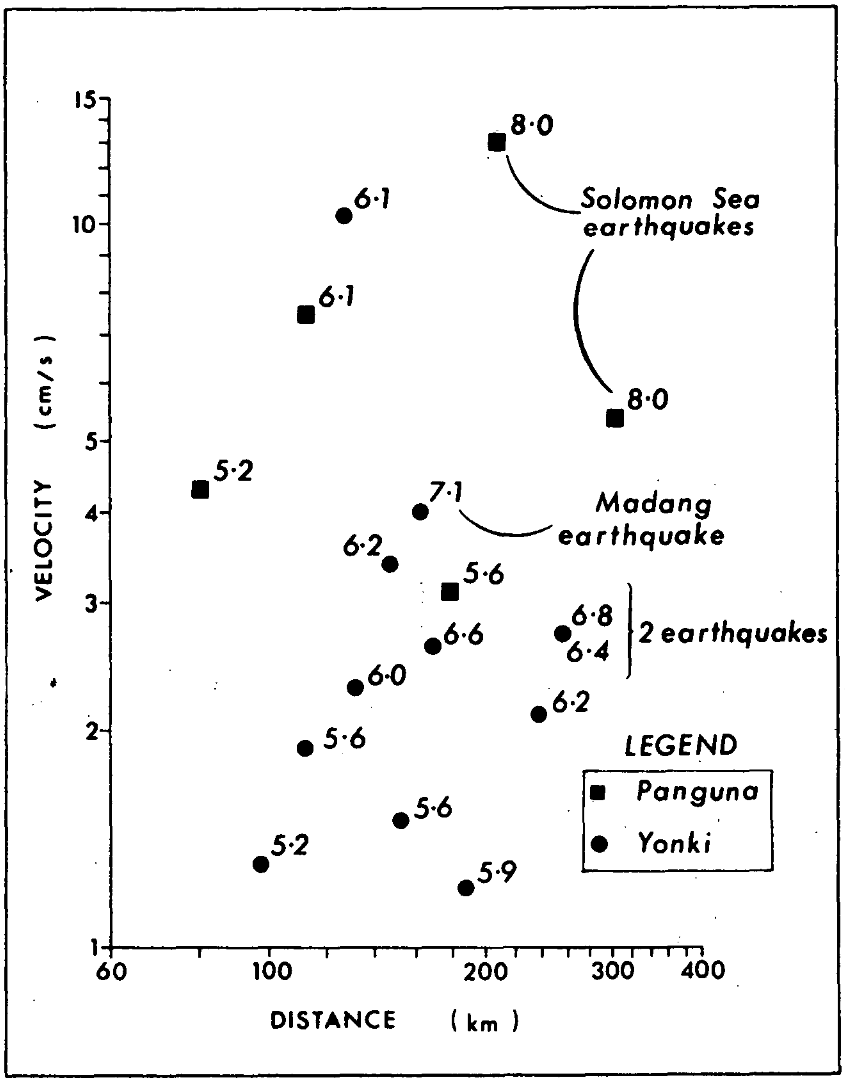
EARTHQUAKES ▲ WHICH TRIGGERED PANGUNA ACCELEROGRAPH

PLATE 4



MAXIMUM ACCELERATIONS, YONKI AND PANGUNA

PLATE 5

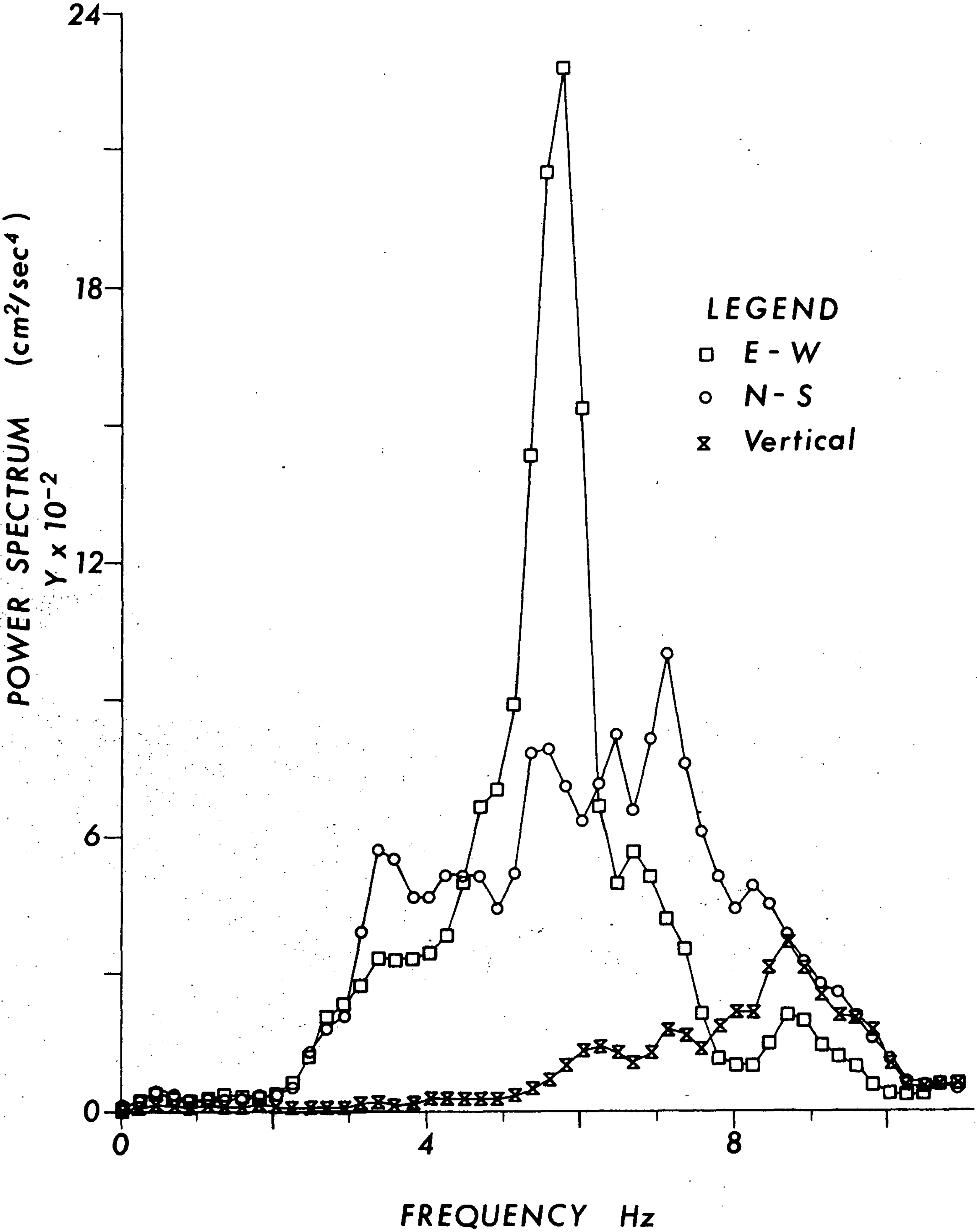


MAXIMUM VELOCITIES, YONKI AND PANGUNA

To accompany record No. 1973/13

PNG/B9 - 195A

PLATE 6



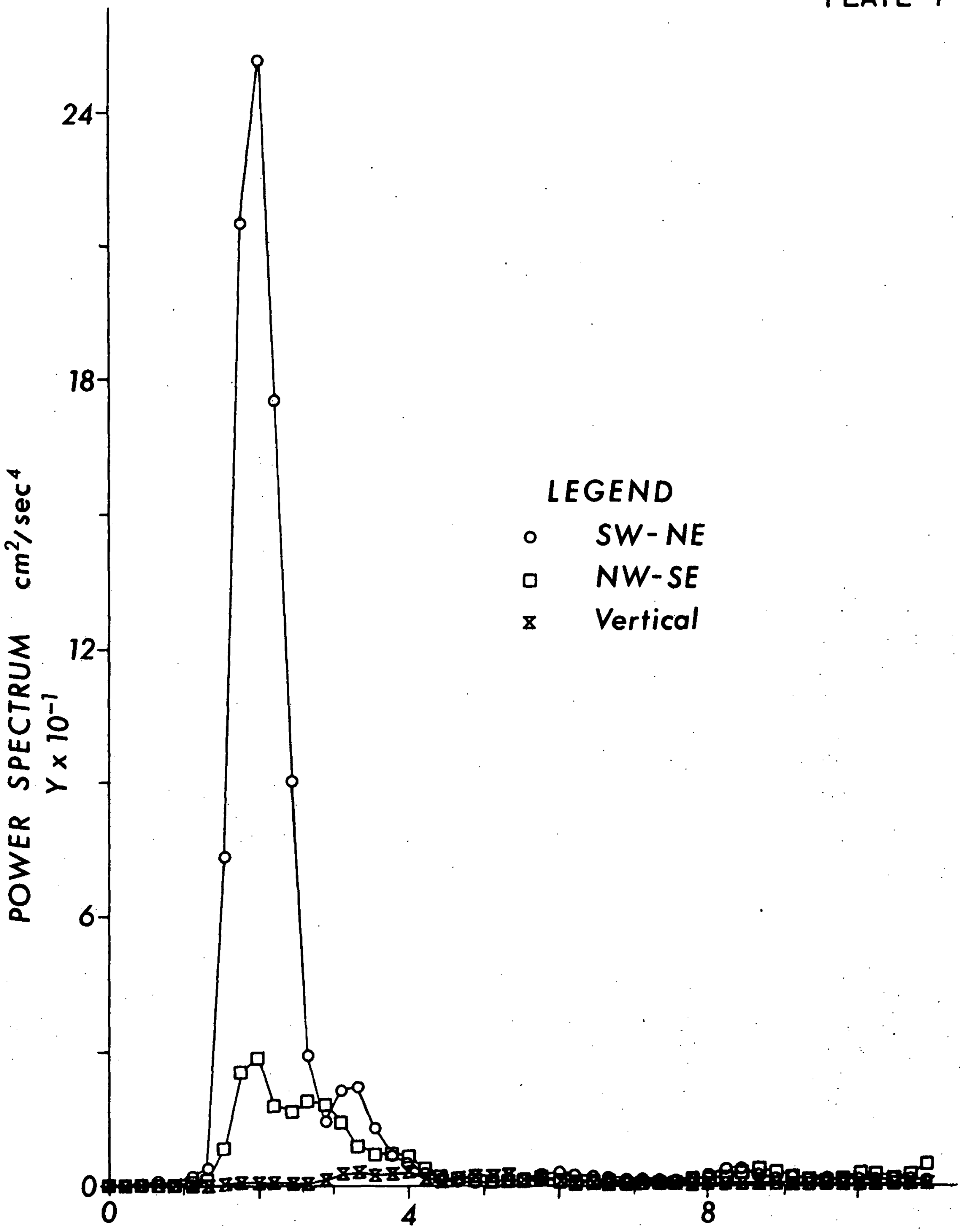
POWER SPECTRUM FROM MADANG

EARTHQUAKE, AT YONKI

To accompany record No. 1973/13

PNG / B9-197 A

PLATE 7

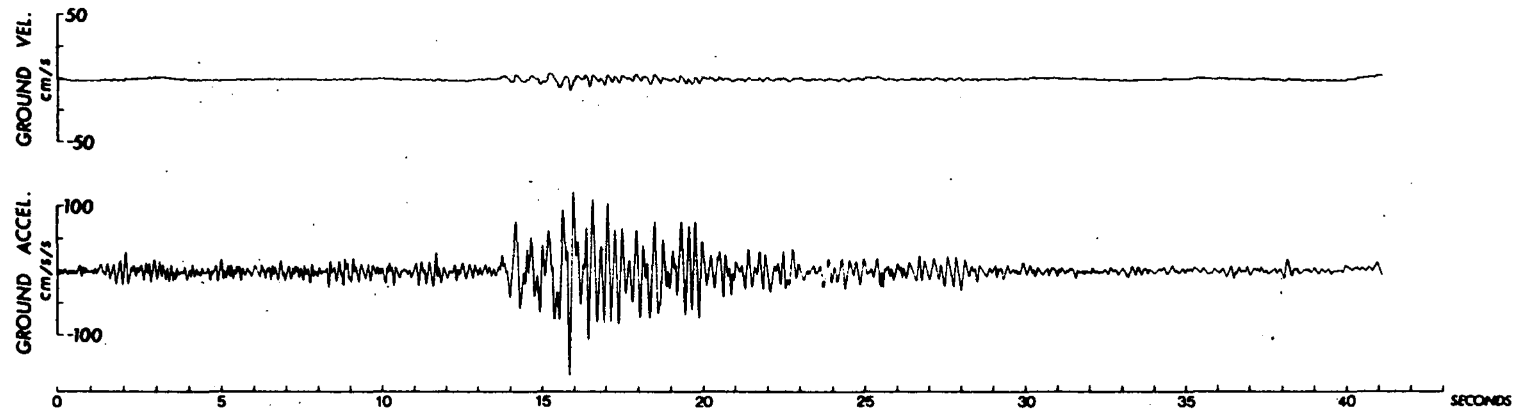


POWER SPECTRUM FROM SOLOMON SEA EARTHQUAKE, AT PANGUNA

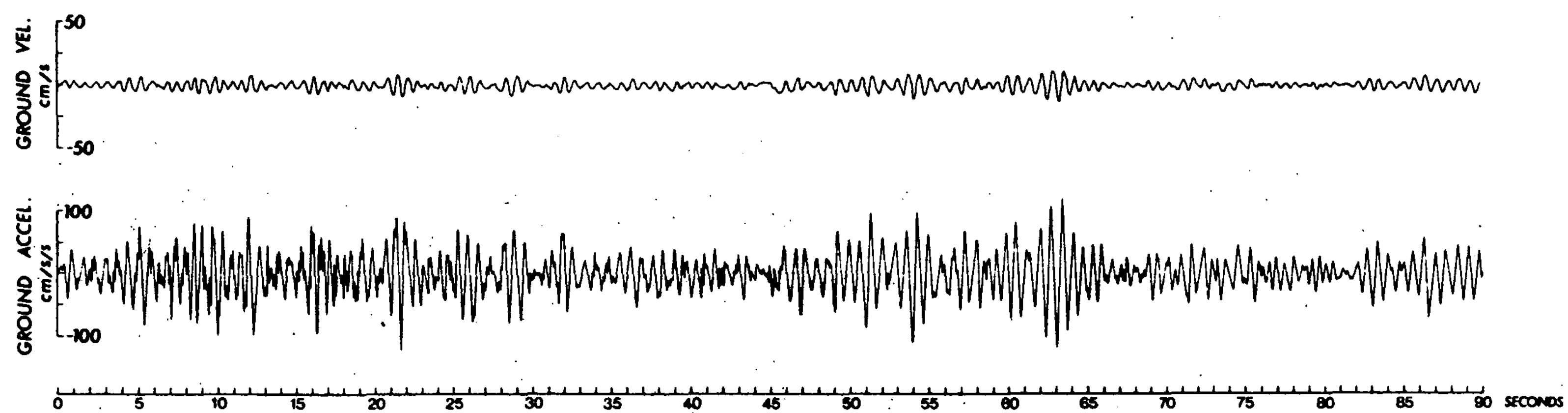
To accompany record No. 1973/13

PNG/B9-196 A

ACCELEROGRAMS FROM YONKI AND PANGUNA



YONKI 13 FEB 1971 H2



PANGUNA SOFT ROCK 14 JULY 1971 HB

PLATE 8

To accompany record No. 1973/13

PNG/B9-198-1A