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BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

Record 1974/82

ACCELEROGRAPH RECORDINGS OF THE MUSA EARTHQUAKE 16 SEPTEMBER 1972

by

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SUMMARY

On 16 September 1972 at 04 15 09.8 UT an earthquake of magnitude ML 5.0 occurred in southeast Papua within about 20 km of a proposed dam site on the Musa River. The earthquake triggered two accelerographs, Musa A and Musa B, one at the crest and one at the base of the dam site. The peak ground accelerations recorded by the accelerographs were 1.85 m/s^2 and 0.39 m/s^2 respectively; the peak ground velocities were 87 mm/s and 20 mm/s; and the corresponding mean periods of the ground motion were about 0.23 and 0.04 s.

The difference in the nature of the accelerograms is attributed to the differences in the geological and topographical settings of the accelerograph sites. The upper site has an elevation of 406 m and consists of about 60 m of weathered sediments overlying fresh ultramafics. The lower site has an elevation of 112 m and consists of an outcrop of the ultramafic complex.

1. INTRODUCTION

In June 1972, the Bureau of Mineral Resources, Geology and Geophysics (BMR), installed 2 accelerographs (hereafter called "Musa A" and "Musa B"), 600 m apart, one on weathered sediments on the crest of one of the abutments, and one on hard ultramafic rock at the base, of a proposed dam site on the Musa River in southeast Papua (Plates 1 and 7, Table 1).

At about 04 15 10 UT on 16 September 1972 an earthquake of magnitude ML 5.0 occurred within 20 km of the dam site and triggered the accelerographs. Despite the closeness of the accelerographs, the accelerograms differ in both acceleration amplitude and period. Plates 2 and 3 show the results of digitization of the accelerograms.

The triggerings were significant insofar as this was the first time in Papua New Guinea that two strong-motion instruments recorded simultaneously on nearby hard and soft rock sites.

2. GROUND MOTION AT THE ACCELEROGRAPH SITES

Table 2 lists the maximum ground acceleration and velocities in the vertical, north-south, and east-west directions; and the periods of ground motion at the times of maximum acceleration.

The resultant ground motions were obtained by vectorial analysis, and by the method outlined by Ambraseys (1969), wherein it is maintained that the maximum resultant acceleration is, on the average, larger by 5% than the maximum component and that the maximum resultant velocity is about 15% larger than the maximum component.

Accelerations greater than 0.3 m/s^2 (0.03 g where g is the acceleration owing to gravity) were recorded for about 11 seconds by the Musa A accelerograph. This duration was confirmed by an observer who was near the Musa A site at the time of the earthquake. He said 'heavy shaking was experienced for five seconds followed by a pause of one second and then a further five seconds of lesser intensity' (Appendix 1).

Accelerations greater than about 0.15 m/s^2 were recorded for a duration of about 5.5 seconds at the Musa B site. This was supported by two observers at a site similar to and near Musa B, who reported that the simply constructed timber building in which they were seated shook noticeably for about 6 seconds (Appendix 1). Accelerations greater than 0.3 m/s^2 were sustained for only about 2 s. Plates 2 and 3 show the derived ground acceleration and velocities at the two sites.

3. EARTHQUAKE HYPOCENTRE AND PROPAGATION PATH

The earthquake hypocentre has been computed by both the United States Environmental Research Laboratories (ERL) and BMR (Appendix 2). Plate 1 shows the epicentres, which are separated by about 7 km. In addition to the data used for the ERL solution, BMR used the two closest seismograph stations, Mt. Lamington (LMG) and Esa'ala (ESA), but the LMG arrival was anomalous. Large uncertainties were encountered in the depth of the earthquake in both computations (Appendix 2) because there was no seismograph close to the epicentre.

Neither the ERL nor the BMR hypocentral determinations used the S-P time difference (the difference between the Primary and Secondary seismic wave arrival times) of 2.5 s recorded by both accelerographs at the dam site. Assuming a P-wave crustal velocity of 5.5 km/s and a P/S velocity ratio of 1.70, the 2.5 s time difference corresponds to a hypocentral distance of 19 km from the dam site.

Hence the earthquake hypocentre lies somewhere on the surface of an imaginary hemisphere of radius about 19 km whose centre is at the dam site. Because the distance between the accelerographs is small (0.6 km) compared to this hypocentral distance, it is assumed that the propagation paths to the two accelerograph sites were identical. Consequently differences in recorded ground motion between the two sites are attributed to receiver site effects alone.

4. GEOLOGY OF THE ACCELEROGRAPH SITES

The main structural units in the area are shown in Plate 4. They include the Musa Basin and the Didana Range Block, which, between them, form a grabenhorst system trending northeast (Davies, 1971). The accelerographs are situated in the Didana Range Block.

The two main lithological units are the Domara River Beds and the Didana Ultramafic Complex (Macias, 1971). The fresh to slightly weathered Didana Ultramafic Complex, which outcrops at the Musa B site, comprises mainly olivine-pyroxene rocks and forms part of the Papuan Ultramafic Belt (Davies, 1971). Elesewhere it is non-conformably overlain by deeply weathered agglomerate, tuff, and interbedded mudstone, siltstone, and conglomerate of the Domara River Beds (Macias, 1971). A seismic traverse (Pettifer et al., in prep.) and drill hole DDR, (Macias, pers. comm.) which are located about 300 m from the Musa A site, suggest that the Domara River Beds are 60 m thick beneath this site (Appendix 3, Plate 5).

5. THEORETICAL MODEL TO ACCOUNT FOR ACCELERATION AMPLIFICATION IN LAYERED SYSTEMS

Madera (1970) outlined a theoretical method to predict the fundamental period of the seismic waves and the amplification of seismic acceleration in soil profiles above bedrock. He obtained good agreement between computed and measured values. The principle is that resonance of seismic waves is set up in the layered system above bedrock, which amplifies the incoming signal. Because it is a resonance affect, the dominating period of the accelerogram should be the fundamental period of the layered model.

On application of Madera's (1970) method to the profile and parameters in Appendix 3, a fundamental period of about 0.26 s was computed for the Musa A site. This value compares reasonably well with the measured mean Musa A accelerogram period of 0.23 s at the time of peak acceleration (Table 2, Appendix 4).

The amplification of acceleration at Musa A could be related directly to the acceleration at Musa B, as the basement rock beneath the overburden at Musa A is the same type of rock which outcrops at Musa B. Using Madera's (1970) method, an amplification ratio of about 2 was obtained (Appendix 4).

When extreme estimates of layer density and internal damping were substituted, the maximum possible amplification ratio attainable was 2.7, which is still significantly less than the measured acceleration ratio of 4.5. Hence Madera's (1970) model does not fully account for the amplification of acceleration which took place at the Musa A site.

6. TOPOGRAPHICAL FACTOR

Davis & West (1973) have observed the effects of topography on ground motion at station sites carefully selected so that the only difference between them was topography. Their results indicate that the amount of amplification and the periods at which it occurs vary with the size of the mountain, and are probably a function of the relation between the wavelengths of the incoming seismic signal and the dimensions of the mountain. The suggested causative mechanism for this amplification is resonance of the mountain set up by shear waves when the wavelength of these waves are of the same order as the dimensions of the mountain.

Musa A and B sites are located respectively near the crest and base of a 400 m high mountain (Plates 5 and 7). Assuming a shear wave velocity of 3.5 km/s and using a period of 0.25 s (corresponding roughly to the period at peak acceleration) a wavelength of about 900 m is obtained, which is about the half the width of the mountain. Using the results obtained by Davis & West (1973) for a mountain of similar size (Mt Butler, Nevada), it was found that the average amplification ratio of ground motion at the crest relative to the base was about 2.5.

Hence the total amplification ratio of the ground motion at Musa A relative to Musa B when the combined effect of lithological and topographical factors are taken into account has been theoretically estimated at about 5, which is in reasonable agreement with the measured ratio of about 4.5.

7. CONCLUSIONS

1. An earthquake of magnitude ML 5.0 triggered the two accelerographs at the Musa River dam site on 16 September 1972. The maximum resultant acceleration recorded by the Musa A accelerograph at the crest of the dam was 1.85 m/s^2 at a period of 0.23 s. An acceleration in excess of 0.3 m/s^2 was sustained at the site for about 11 s. The maximum resultant acceleration recorded by the Musa B accelerograph at the base of the dam site was 0.39 m/s^2 at a period of 0.04 s. An acceleration in excess of 0.3 m/s^2 was sustained for about 2 seconds.

2. There is an uncertainty of about 20 km in the earthquake hypocentre determination. However the 2.5 s S-P time interval on the accelerograms indicates that the separation between the earthquake hypocentre and the dam site was about 19 km.

3. The 4.5:1 ratio of amplitude of ground acceleration which occurred at the Musa A site relative to that of the Musa B site can be explained by the combined effect of the lithology and topography.

8. REFERENCES

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TABLE 1

1. INSTRUMENT DATA

INSTRUMENT NAME	TYPE	BLOCK NO.	CALIBRATION* DATA (g/cm)	OWNER
MUSA A	MO2	446	EW 0.589 NS 0.638 Z 0.393	BMR
MUSA B	MO2	117	EW 0.627 NS 0.634 Z 0.408	BMR

* g = acceleration owing to gravity

2. SITE DATA

PLACE	CO-ORDINATES	ELEVATION (m)	FOUNDATION
MUSA A	9.556°S 148.674°E	406	Domara River Beds (Pleistocene)
MUSA B	9.556°S 148.679°E	112	Didana Ultramafic Complex

TABLE 2

Summary of ground motion at Musa Gorge 16 September 1972

Component	Max accel. m/s^2	Max velocity mm/s	Period (s) P wave	Period (s) S wave
MUSA A				
Z	0.28	7	0.11	0.14
NS	0.78	46	0.09	0.22
EW	1.66	74	0.09	0.25
Vector resultant	1.85	87	Mean	0.23
Ambraseys resultant	1.74	85		
MUSA B				
Z	0.01	1.3	0.03	0.04
NS	0.39	1.4	0.03	0.04
EW	0.03	0.6	0.03	0.05
Vector resultant	0.39	2.0	Mean	0.04
Ambraseys resultant	0.41	1.6		

APPENDIX 1

REPORTS ON EARTHQUAKE AT MUSA
16 SEPTEMBER 1972

1. Mr. B. Greentree (Surveyor, CDW, Port Moresby)

At the time of the earthquake Mr. Greentree was at the Stream Gauging Station on Musa River about 800 m from the Musa B accelerograph. The geological foundation at the Station is rock outcrop similar to the Musa B site. He said that the mess building shook noticeably for 6 s and then it was all over. He reported that there was no noise before of after the shock. He also said that should the shaking have continued, it would have upset unstable objects.

2. Mr. Glauco (Surveyor, CDW, Port Moresby)

Mr. Glauco was also at the Stream Gauging Station. He supported the above statements and added 'It was like an overloaded washing machine'.

3. Peter Brent (Engineer, CDW, Melbourne)

Mr. Brent was about 50 m from the Musa A accelerograph at the time of the earthquake. He was sitting down, but others near him remained standing even though the ground motion was strong.

He also answered the following questions:

(a) Q. Did you feel ground motion tending to affect standing up?

A. There appeared to be no problems for those standing.

(b) Q. On the telephone conversation you used the word "liquefaction" to describe the ground motion - what did you see?

A. Perhaps liquefaction was the wrong term - it was the first quake of my experience, but the ground seemed to lose its solid property.

(c) Q. Did you notice anything else?

A. The trees seemed to be moving with respect to the ground - none fell over.

(d) Q. Were there any waves in the ground?

A. Did not notice any.

(e) Q. Was there any preferred direction of motion for the ground movements?

A. Did not notice any.

(f) Q. Was there a bang or rumble - any noise at start?

A. Maybe a rumble.

(g) Q. Did you feel one or two main shocks?

A. Heavy shaking for 5 s, then 1-s spacing followed by 5 s of lesser intensity.

APPENDIX 2

THE ERL AND BMR EARTHQUAKE HYPOCENTRES

ERL

Origin Time	=	04 15 09.76 ± 3.47 s
Lat.	=	9.466°S ± 6.6 km
Long.	=	148.664°E ± 7.0 km
Depth	=	4 km ± 22.6 km
Magnitude (MB)	=	5.3 (3 stations)

The precision stated by ERL for the derived parameters is not intended by ERL to reflect their true accuracy. The standard errors represent the intercepts in error space of the computer hypocentre coordinates and are a measure of the goodness of the fit of the least-squares procedure. Most ERL hypocentres are understood to be accurate to a few tenths of a degree in position and 25 km in depth.

BMR

Lat.	=	9.53°S ± 8 km
Long.	=	148.66°E ± 7 km
Depth	=	Restrained to 0.0 km

The depth control is poor, but the hypocentre is evidently shallow as negative depths were obtained in the initial iterations.

APPENDIX 3

THE ASSUMED MUSA A PROFILE

The information has been extracted from Hole DDR (Macias, pers. comm.) and seismic traverses (Pettifer et al., in prep.) shown in Plate 5.

Depth (m)	Layer properties	Thickness
0		
	Cs = 171 m/s $\gamma = 2.2 \times 10^3$ kg/m^3	H_1 = 1 m
1		
	Cs = 285 m/s $\gamma = 2.5 \times 10^3$ kg/m^3	H_2 = 5 m
6		
	Cs = 456 m/s $\gamma = 2.25 \times 10^3$ kg/m^3	H_3 = 18 m
24		
	Cs = 1311 m/s $\gamma = 2.35 \times 10^3$ kg/m^3	H_4 = 37 m
61		
	Cs = 2565 m/s $\gamma = 2.8 \times 10^3$ kg/m^3	

Notation

Cs = seismic shear wave velocity

γ = density of rock layers

H = thickness of layer

An average internal damping (Di) of 5% is assumed for the system.

Density values are estimates supplied by Macias (pers. comm.) who examined the drill cores.

APPENDIX 4

CALCULATION OF MUSA DATA (AFTER MADERA, 1970)

1. Fundamental Period (T) of layered system

$$C = \frac{\sum_{i=1}^{4} C_i H_i}{\sum_{i=1}^{4} H_i}$$

where C = average S wave velocity in layered system
Ci = S wave velocity in ith layer
Hi = thickness of ith layer

= 956 m/s

$$T = \frac{4H}{C}$$

where H = total thickness of layers

= 0.26 s

2. Average density (γ) of layered system

$$= \frac{\sum_{i=1}^{4} \gamma_i H_i}{\sum_{i=1}^{4} H_i}$$

where γi = density of ith layer
Hi = thickness of ith layer

= 2.33×10^3 kg/m^3

3. Impedance ratio (I.R.)

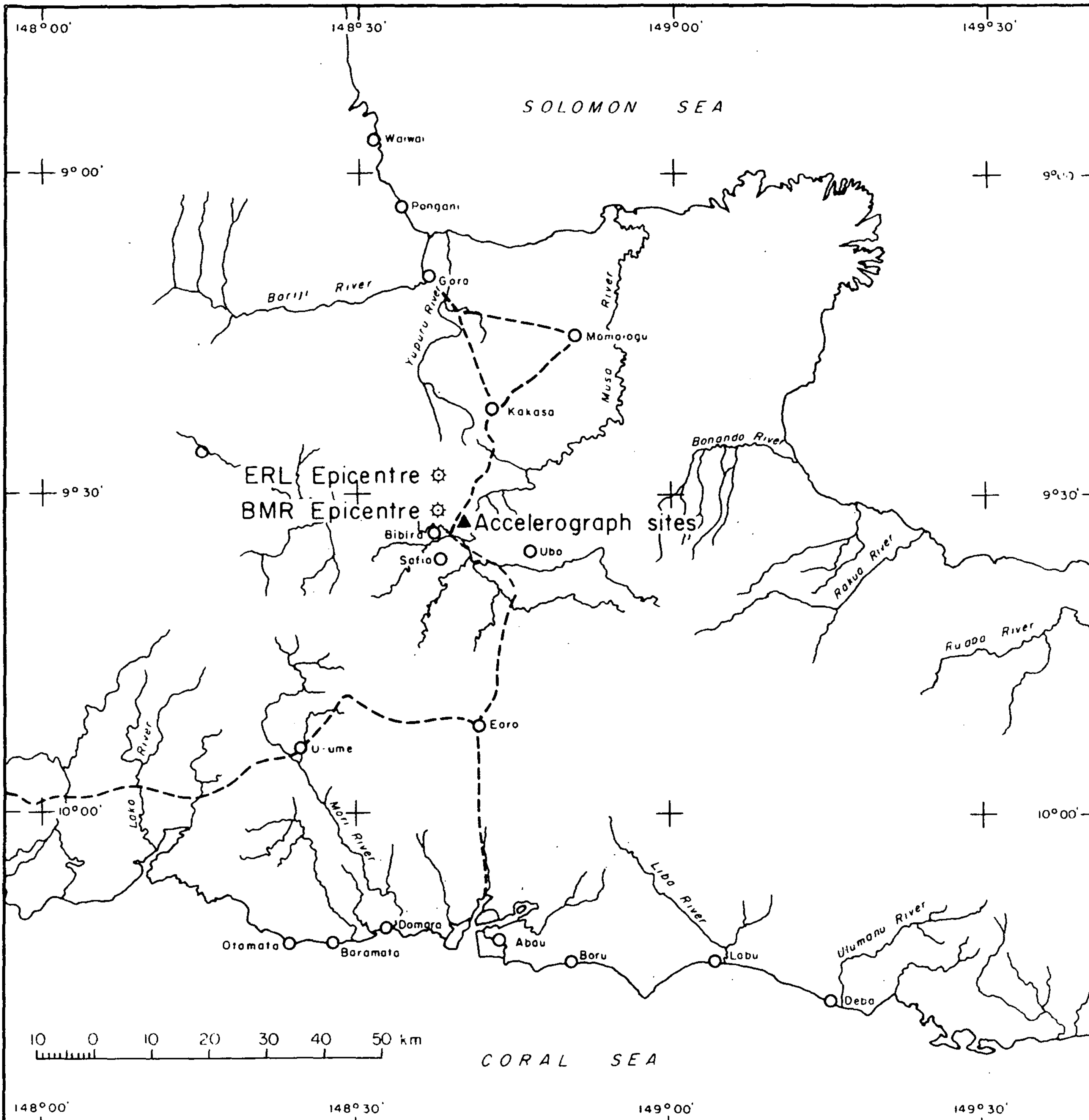
$$= \frac{\gamma_R C_R}{\gamma C}$$

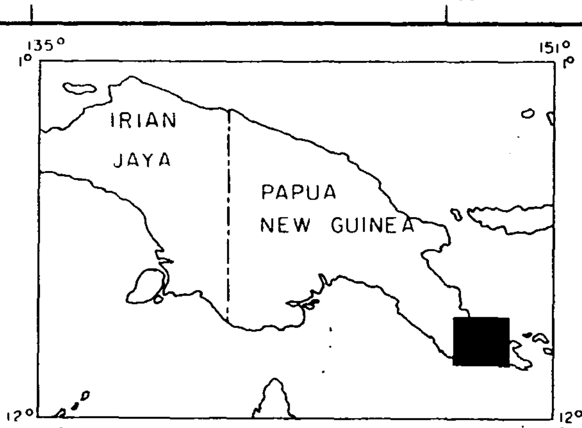
where γ_R = density of bedrock
C_R = S wave velocity in bedrock

= 3.2

when I.R. = 3.2
Di = 5%
and T = 0.26 s

From Plate 6 an approximate amplification factor of 4 is obtained.





LOCALITY MAP OF ACCELEROGRAPHS AND COMPUTED EPICENTRES

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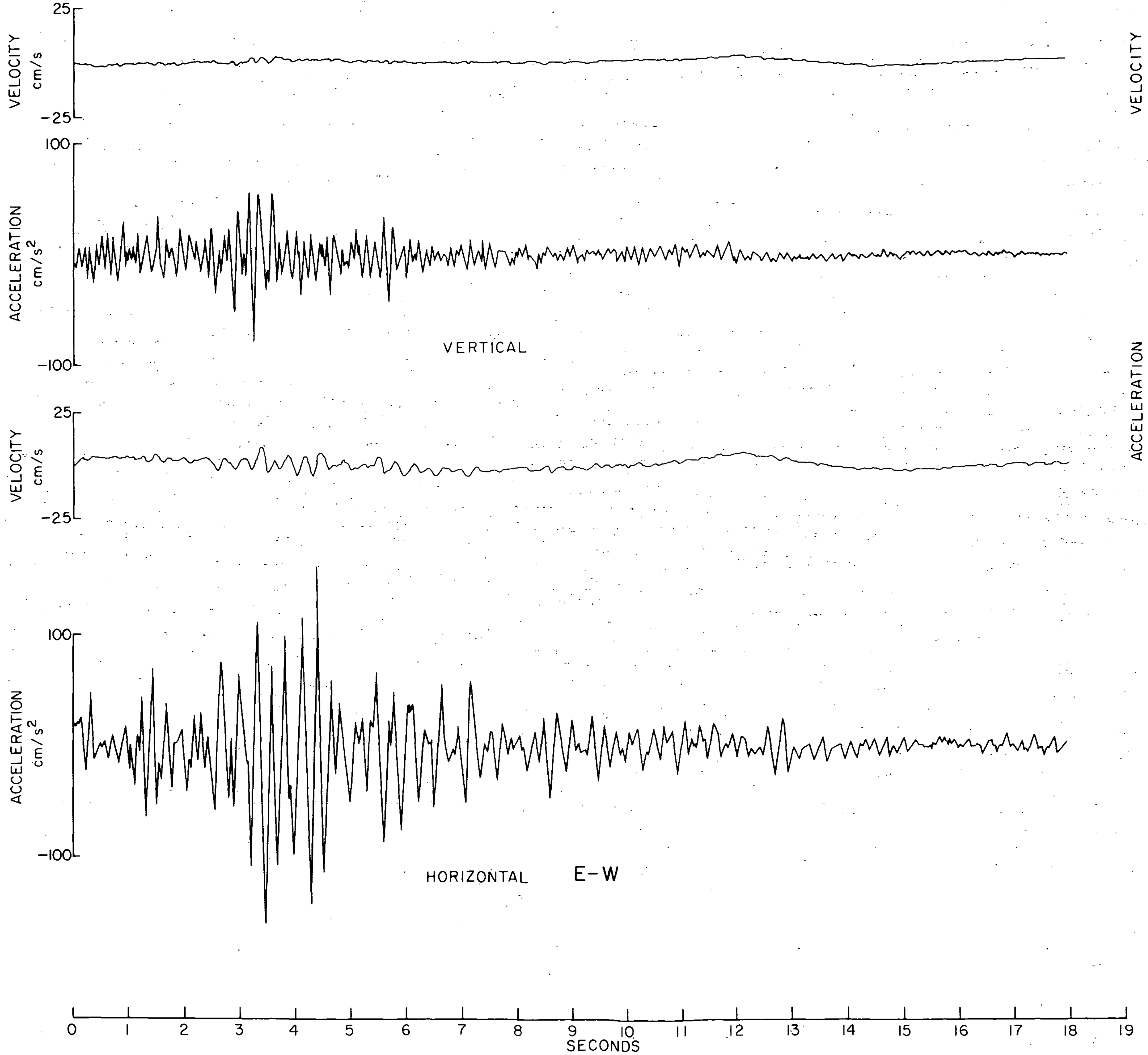
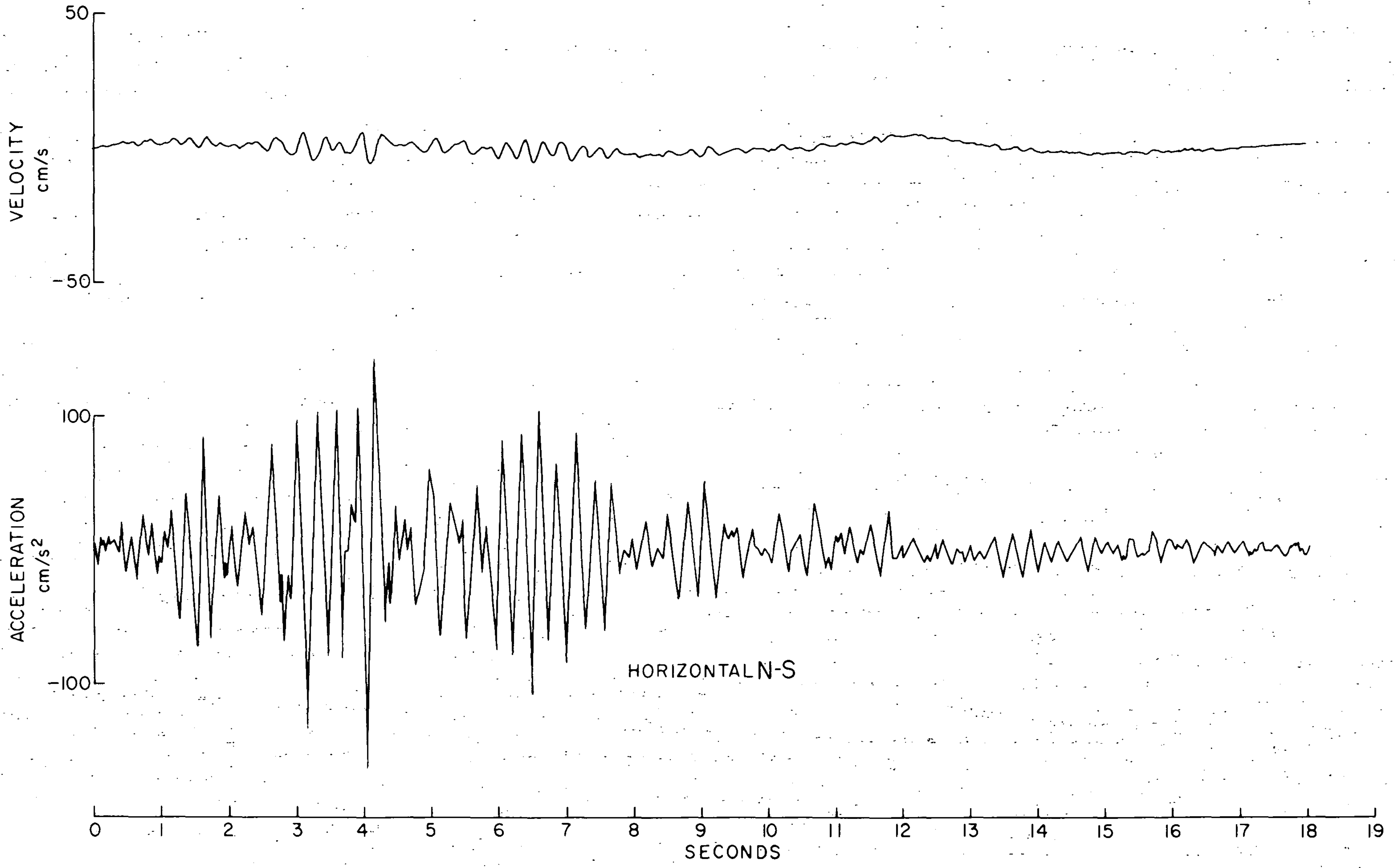
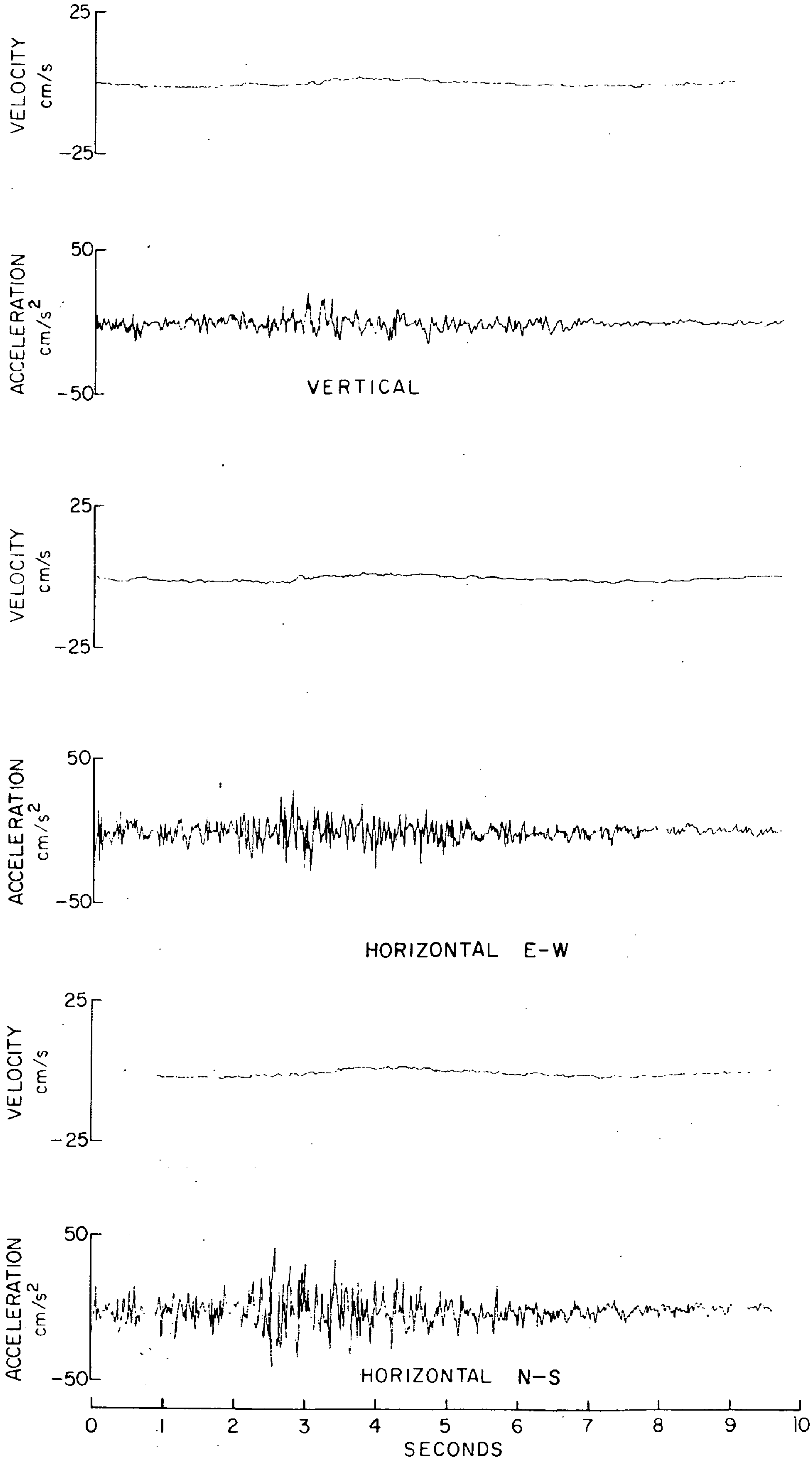
PLATE 2





GROUND MOTIONS FROM MUSA A ACCELEROGRAPH

PLATE 3



GROUND MOTION FROM MUSA B ACCELEROGRAPH

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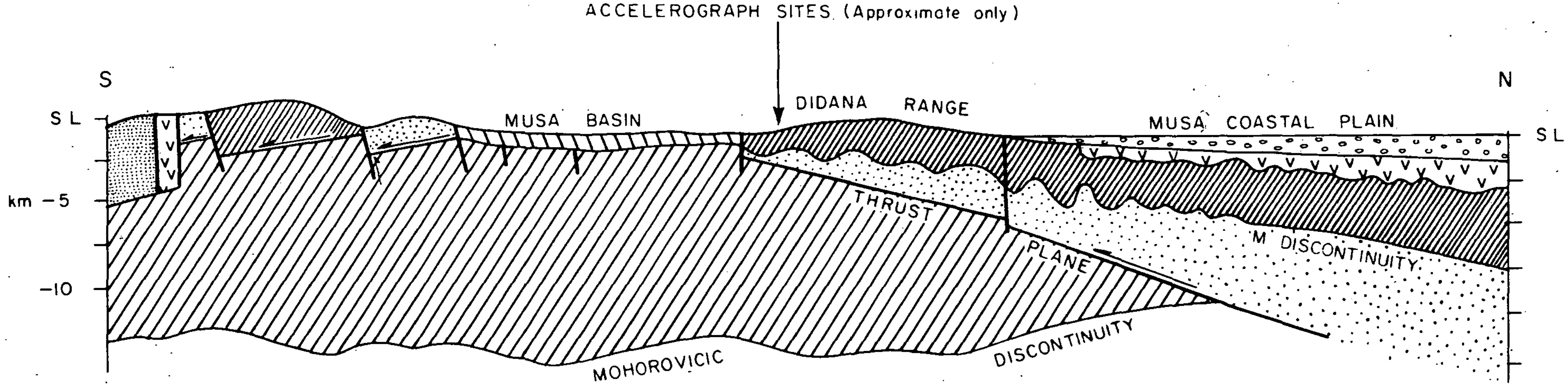
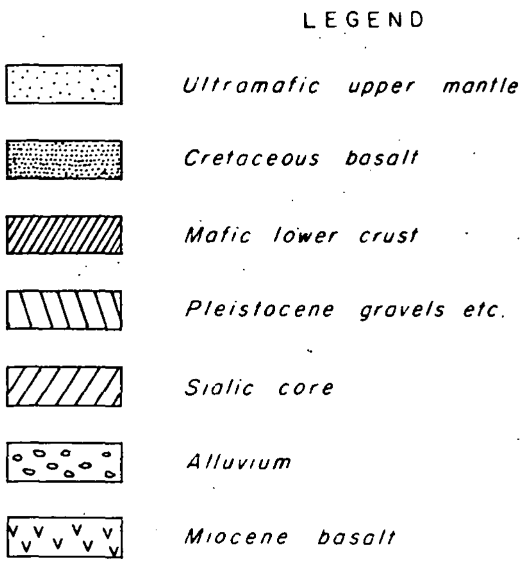
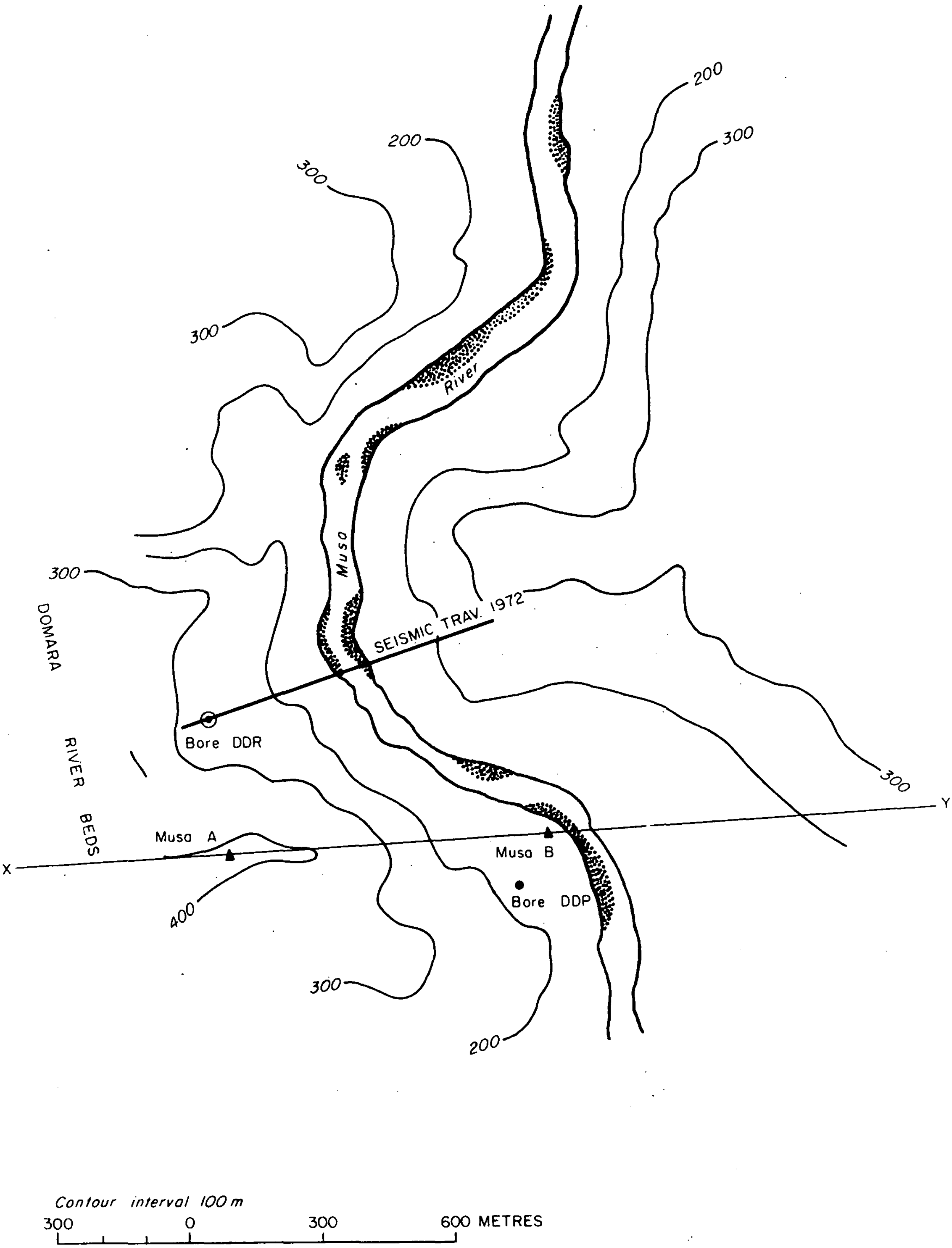




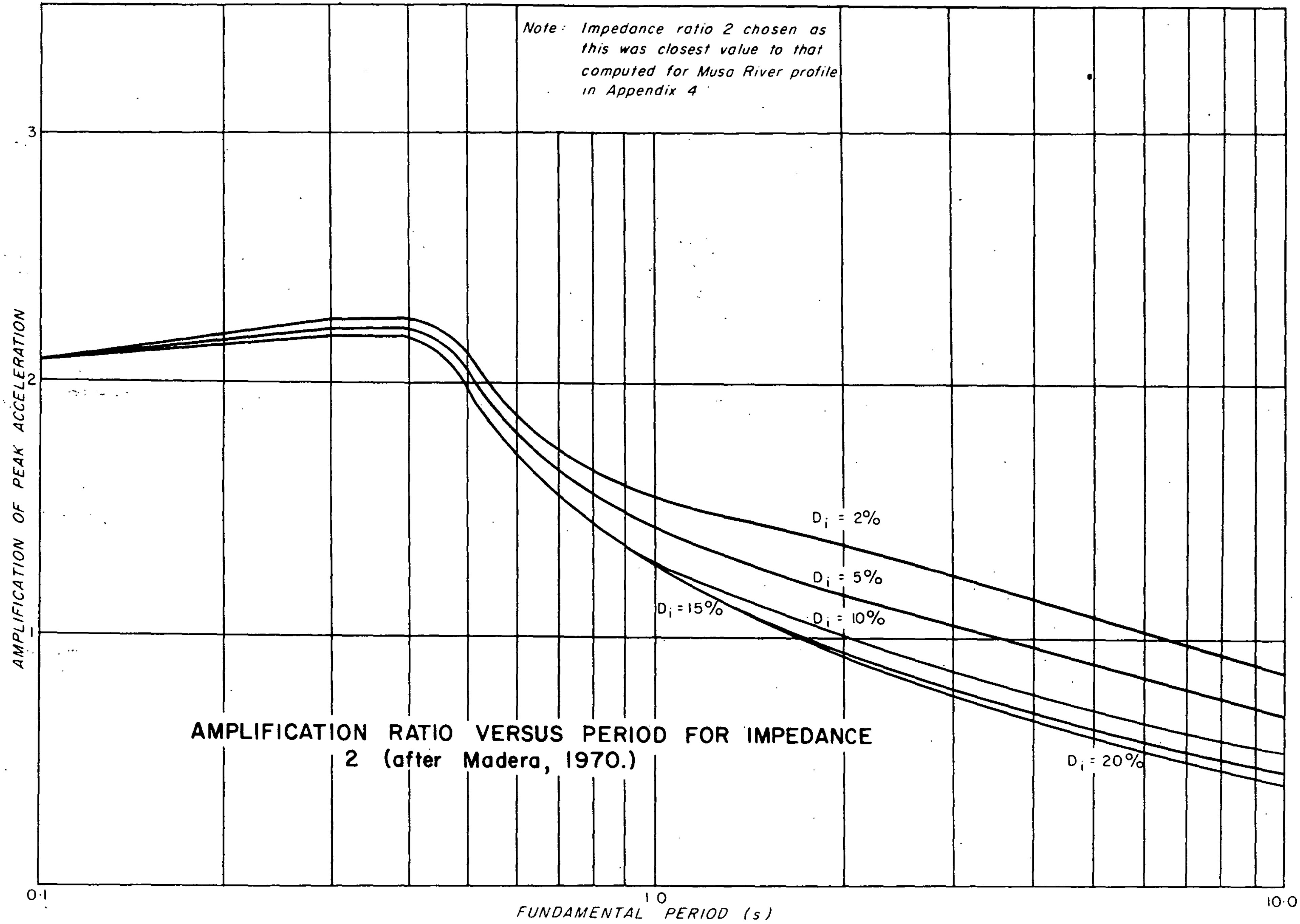
SCHEMATIC CROSS-SECTION THOUGH PAPUAN ULTRAMAFIC BELT IN THE REGION OF THE DAM SITE (after Davies, 1971)

C55/B9-4A

PLATE 4



MUSA RIVER DAM SITE TOPOGRAPHIC CONTOURS, BORE-HOLES AND SEISMIC TRAVERSE



AMPLIFICATION RATIO VERSUS PERIOD FOR IMPEDANCE 2 (after Madera, 1970.)

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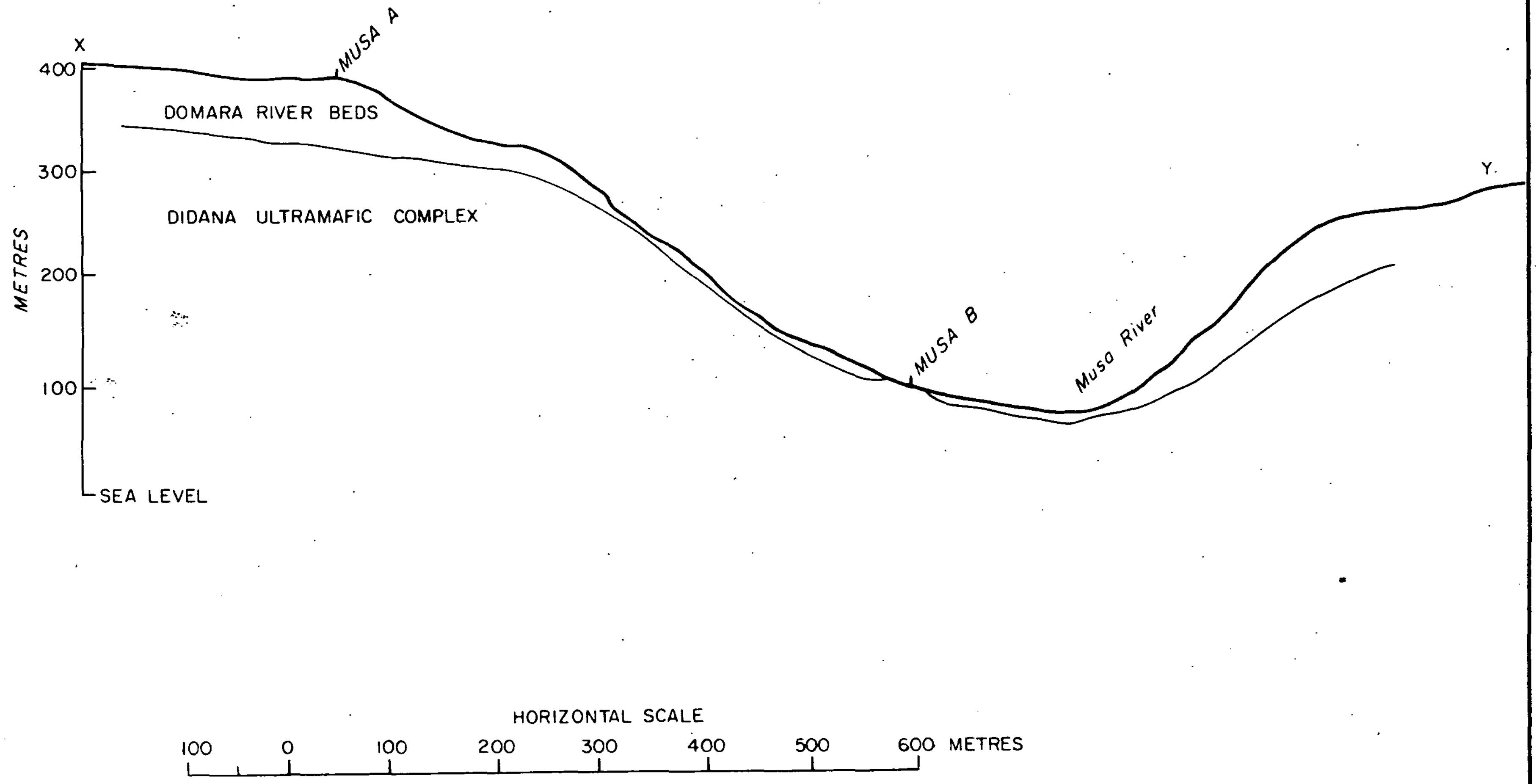

CROSS-SECTION THROUGH ACCELEROGRAPH SITES ILLUSTRATING TOPOGRAPHY AND APPROXIMATE DEPTH TO BEDROCK

C55/B9-7A

PLATE 7