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Waveform Data from Aftershocks of the 1990 Upland, California Earthquake Recorded on a Small-Aperture Seismic Array

by

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ABSTRACT

A small array of five stations was installed 4 km south-southeast of the epicenter of the February 28, 1990 Upland earthquake (M_L5.2). Velocity and acceleration data recorded at 200 samples per sec were collected on stations that were spaced at 100 to 150 meters intervals. The array was operated from March 2 to March 20, recording 221 events of magnitude 1.0 to 3.4 at hypocentral distances of 4 to 14 km. Clear S waves can be seen on all of the events, which will help to constrain the depth of the aftershocks. Significant differences in the amplitude and waveforms between these closely spaced stations show the strong effects that site response has on high-frequency data.

INTRODUCTION

On February 28 at 23:43 GMT, a $M_L5.2$ earthquake occurred near the towns of Upland and Claremont, California ($34.14^oN, 117.70^oW$). There was some damage in the areas of Upland, Claremont and Pomona, consisting mainly of broken windows and some structural damage to buildings. The total damage was estimated to be $12.7 million (National Earthquake Information Center). From the focal mechanism and the aftershock locations, the faulting was inferred to be mainly left-lateral strike-slip motion on the northeast trending San Jose fault (Hauksson and Jones, 1991). Following the earthquake, a small aperture array of five seismic instruments was installed at Cable Airport, located about 4 km south-southeast of the epicenter in Upland, California (Fig.1). The array was installed for several purposes,

1. To record S waves at close epicentral distances so that more accurate depths could be determined for the aftershocks. At the time of the mainshock, the closest permanent seismic station was a vertical component site about 9 km to the north.

2. To record strong ground motions from any damaging earthquakes that might follow the February 28th event.

3. To record waveforms from closely spaced stations in order to study the coherence of high-frequency seismic data.

The array was in operation from March 2 until March 20, recording 221 events. Most of the earthquakes had magnitudes between 1.0 and 3.0 with three events over magnitude 3.0 (3.1, 3.3 and 3.4). Epicentral distances were from 0.3 to 7.7 km (hypocentral distances of 4 to 14 km).

This report describes the data collection of the Cable Airport array and shows some examples of the waveforms recorded. All the data are available from the Pasadena Office of the U.S. Geological Survey.

CABLE AIRPORT ARRAY

The stations of the array consisted of three-component velocity and acceleration sensors recorded on GEOS (General Earthquake Observations System, Borcherdt et al., 1985) instruments with 16 bit resolution at a sample rate of 200 hz. The velocity sensors were

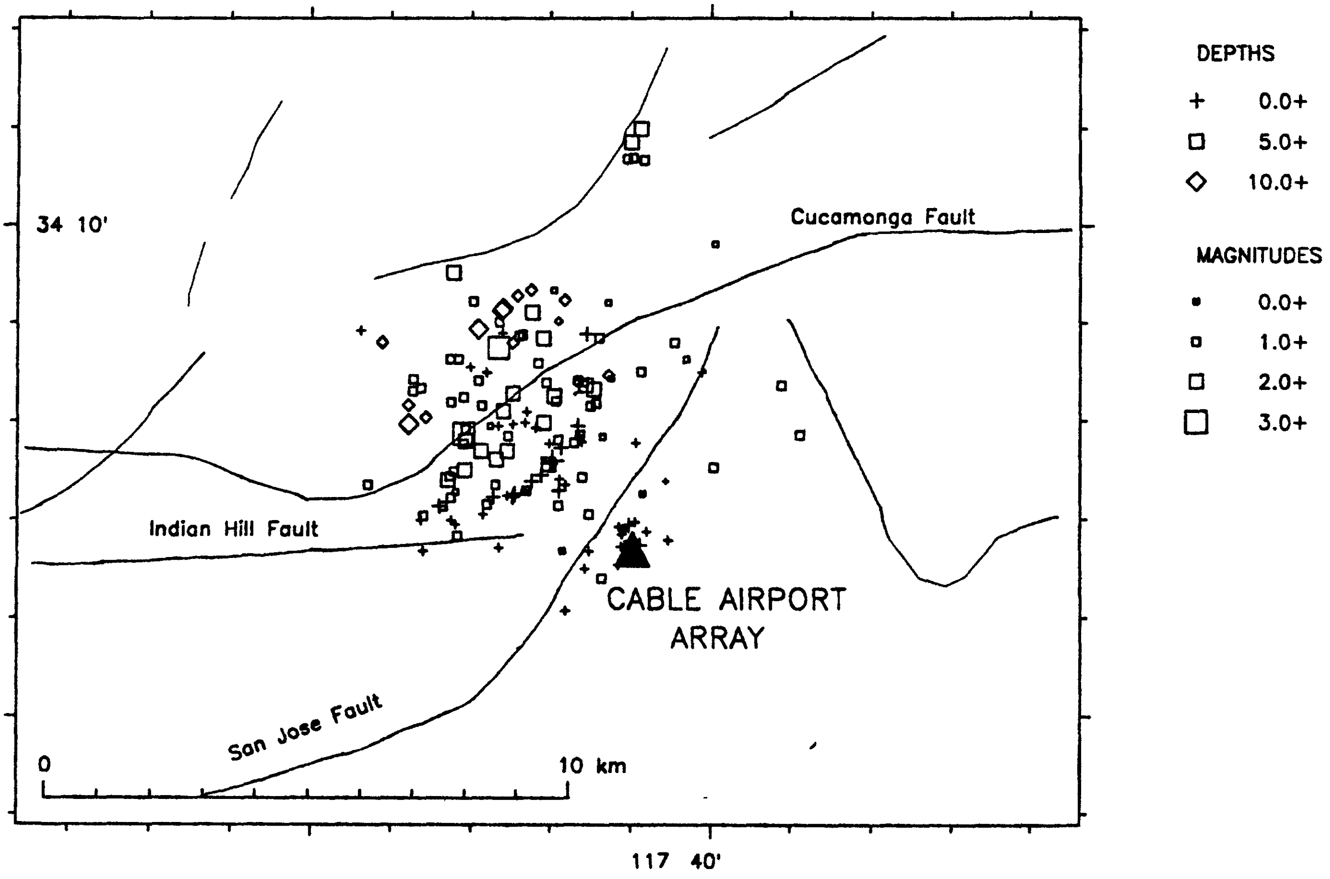

Fig. 1. Locations of the Cable Airport Array and the recorded earthquakes.

Mark Products L22 seismometers with a natural frequency of 2 hz, and the accelerations sensors were Kinemetrics FBA-23 force balance accelerometers.

The five sites were located in the configuration shown in Fig. 2, with station spacings of 100 to 150 meters. All of the sensors were placed on concrete slabs which formed the floors of airplane hangers or one-story storage buildings. The relative locations of the stations were determined from a 1:1200 scale survey map of the airport and the absolute location of the array was read from a 1:24000 scale USGS quadrangle map. The station coordinates are given in the following Table 1.

STATION	LAT.	LONG.	ELEVATION (M)
CB1	$34.11363^o N$	$117.68326^o W$	437
CB2	$34.11312^o N$	$117.68472^o W$	436
CB3	$34.11407^o N$	$117.68424^o W$	439
CB4	$34.11245^o N$	$117.68210^o W$	431
CB5	$34.11148^o N$	$117.68208^o W$	427

Table 1. Stations coordinates for the Cable Airport Array.

While the array was operating from March 2 to March 20, there are waveform data from at least two stations for 146 of the 447 events located by the Southern California Seismic Network. In addition the array recorded good waveform data for 74 events not detected by the permament network. The trigger sensitivity of the instruments varied during the deployment, and the number of events recorded changed accordingly. For example, from March 2nd to 3rd, when the trigger threshold was at a relatively low level, the array recorded data on two or more stations for more earthquakes than were located by the permanent network. During that time the array recorded data for 79 of the 112 events located by the permanent network plus 57 events not detected by the permanent network. All of the trigger and recording parameters are listed in Table 2.

The table in Appendix 1 lists all of the recorded events and available hypocentral and magnitude information as determined by the Southern California Seismic Network. The distribution of epicenters for the located events is shown in Fig. 1.

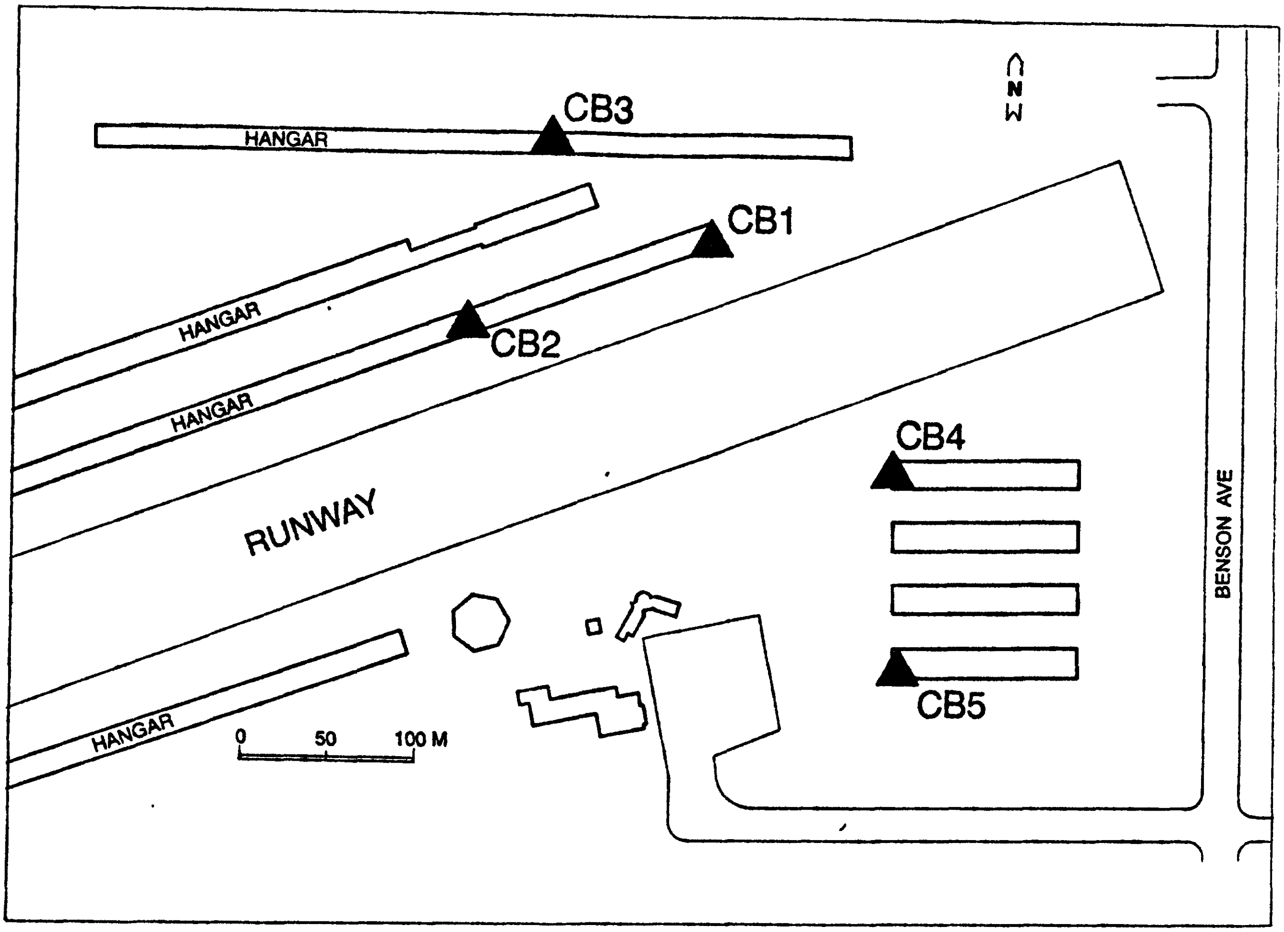

Fig. 2. Station configuration of the Cable Airport Array.

	FBA GAIN (db)	VEL. GAIN (db)	LOW-PASS FILTER (hz)	LONG-TERM AVG. (sec)	SHORT-TERM AVG. (sec)	THRESHOLD RATIO
DAY 61 19:00	12	36	50	10	0.4	8
DAY 63 19:00	12	36	50	10	0.4	16
DAY 64 20:30	12	36	50	10	0.4	32
DAY 66 04:00	12	36	50	10	0.4	16

Table 2. GEOS recorder settings

JULIAN DAY	CB1	CB2	CB3	CB4	CB5
61	+0.0 (18:14)	-22.0 (18:45)	-22.0 (19:12)	+ 0.0 (19:45)	-22.0 (22:04)
62	-5.0 (17:23)	-16.2 (17:46)	-20.6 (18:00)	+ 1.8 (18:30)	-25.5 (18:50)
63	-3.8 (17:30)	-22.1 (17:25)	-29.2 (17:16)	+ 1.9 (17:36)	-19.9 (17:42)
64	-7.1 (20:39)	-18.4 (20:22)	-23.3 (20:51)	+ 2.2 (21:36)	-28.8 (21:23)
68	-23.2 (19:30)	-19.2 (19:16)	-28.9 (18:30)	+15.8 (19:47)	-32.9 (20:08)
72	-27.4 (17:57)	+770.8 (17:49)	-47.7 (17:41)	+34.9 (18:05)	
73	-29.2 (17:53)	+774.2 (18:10)	-57.7 (18:25)	+40.1 (18:34)	

Table 3. Clock corrections (milleseconds) recorded while array was in operation. The number in parenthesis gives time of day (GMT) that the clock was checked.

The timing of the recorders was calibrated with a master clock developed by the USGS (Healy et al., 1982). At the time of installation, the clocks of the GEOS recorders were set to WWVB for stations CB2, CB3 and CB5 and set to the master clock at stations CB1 and CB4. Subsequently the timing in all the recorders were checked against the master clock at one to three day intervals. The clock corrections are given in Table 3. From day 69 through 73 there was a problem with the clock at CB2 causing the time to be off by a large amount (0.7 sec).

OTHER INSTRUMENTATION NEAR THE EPICENTER

In addition to the Cable Airport Array, strong motion accelographs (Kinemetrics SMA-1) were installed at four sites near the epicenter, within 24 hours following the mainshock. Two of these sites triggered on the M_L4.6 aftershock of March 2 at 17:26 GMT. By March 20, when the Cable Airport array was discontinued, two nearby sites with three-component velocity and acceleration channels had been added to the permanent telemetry system of the Southern California Seismic Network.

WAVEFORM DATA

Appendix 2 shows examples of waveforms from 11 events that were recorded on all five stations. There were intermittant problems with the East/West velocity components at CB2 and CB3, so that there are no data from these components for some of the events. Also, there were problems with CB1 and CB5 during the later period of the deployment, thus limiting the time when all five stations were operating, to before March 8. The long-period signals ($\sim$ 1 sec) on the North/South component of CB3 are probably due to instrument problems.

This data set contains a variety of interesting waveforms from small earthquakes at close epicentral distances. There are simple seismograms with S-P times of less than one sec (e.g. 90 63 23 16) to more complicated seismograms from greater distances (e.g. 90 36 1 36). Even with the close station spacings of the array, there are noticeable differences among the waveforms for both the accelerations and the lower frequency velocities, demonstrating that the site response has a significant effect on the high frequency data. Some preliminary observations,

1. Station CB2 tends to amplify the high frequencies around 10 hz. The P waves are usually a factor of 2 to 3 larger on this station than at the other sites. The acceleration record of 90 63 8 40 shows an unusually amplified P wave which is 5 to 10 times larger than on the other stations.

2. There are some arrivals in between P and S which are seen on the vertical components, which are possible S to P conversions. Stations CB3 and CB4 seem to show these phases best, for example on the acceleration records of 90 62 1 36.

3. The near-field ramp between the P and S waves can be seen in some of the displacement waveforms, such as the North/South component of 90 62 23 21 and the North/South component of 90 63 23 16.

4. The North/South component of the S wave usually arrives before the East/West component by 0.03 to 0.1 sec, indicating anisotropic S-wave velocities.

ACKNOWLEDGEMENTS

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Appendix 1. LIST OF EVENTS RECORDED BY THE CABLE AIRPORT ARRAY

The following table lists all the events that triggered two or more stations of the array. Hypocenters and preliminary magnitudes determined by the Southern California Seismic Network, were taken from the Caltech catalog. For events that were not located by the permanent network, the times are trigger times of the first station. The "NO. STA" column, gives the number of stations with good waveform data.

YR	MO	DAY	JULIAN DAY	HR	MIN	SEC	LAT (N)	LONG (W)	DEPTH (KM)	MAG	DIST (KM)	BACK AZ.	NO. STA
90	3	2	61	19	24	32.77	34.1375	117.6992	5.5	2.1	3.2	332	2
90	3	2	61	20	26	45.72	34.1473	117.7015	8.4	2.7	4.3	337	3
90	3	2	61	20	38	16.54	34.1380	117.7078	7.9	2.5	3.7	322	3
90	3	2	61	21	46	17.59	34.1482	117.6925	4.9	2.0	4.1	348	2
90	3	2	61	22	3	58.80	34.1518	117.7037	9.8	2.2	4.8	337	2
90	3	2	61	23	11	6.59	34.1525	117.7098	11.3	2.1	5.1	331	3
90	3	2	61	23	59	59.61	34.1490	117.7152	11.0	2.1	5.1	324	4
90	3	3	62	0	36	0.20	34.1438	117.7193	6.4	1.9	4.9	317	2
90	3	3	62	1	30	8.17	34.1432	117.7025	6.8	1.5	3.9	333	2
90	3	3	62	1	32	58.00							2
90	3	3	62	1	36	38.80	34.1328	117.7297	11.2	2.3	4.9	298	5
90	3	3	62	1	55	17.13	34.1283	117.7145	6.8	2.1	3.4	302	5
90	3	3	62	3	14	49.01	34.1387	117.6910	5.0	2.1	3.1	346	4
90	3	3	62	3	51	35.35	34.1242	117.7018	4.6	2.1	2.2	308	5
90	3	3	62	5	2	28.83	34.1358	117.6917	5.4	1.5	2.8	343	5
90	3	3	62	5	48	30.20	34.1350	117.7098	7.7	2.2	3.6	316	5
90	3	3	62	6	12	53.00							5
90	3	3	62	6	27	24.75	34.1310	117.6480	5.2	1.4	3.9	57	5
90	3	3	62	6	32	10.42	34.1537	117.7162	6.0	1.5	5.6	327	4
90	3	3	62	6	41	42.15	34.1297	117.6950	5.1	1.5	2.3	331	5
90	3	3	62	6	54	59.02	34.1397	117.6928	5.5		3.2	344	2
90	3	3	62	7	7	2.00							3
90	3	3	62	7	40	47.00							5
90	3	3	62	7	50	19.65	34.1417	117.6813	6.0	1.3	3.3	3	2
90	3	3	62	7	54	43.02	34.1330	117.7013	5.3	2.1	2.9	324	5
90	3	3	62	8	48	28.87	34.1340	117.7262	12.4	1.6	4.7	302	5
90	3	3	62	9	4	8.20	34.1405	117.6875	6.3		3.2	353	5
90	3	3	62	9	42	55.10	34.1238	117.6933	5.0	1.8	1.6	324	5
90	3	3	62	9	46	24.00							2
90	3	3	62	10	22	37.49	34.1478	117.7065	9.9	1.8	4.5	332	5
90	3	3	62	10	46	57.00							5
90	3	3	62	10	51	33.43	34.1585	117.7203	6.8	2.0	6.2	326	5

YR	MO	DAY	JULIAN DAY	HR	MIN	SEC	LAT (N)	LONG (W)	DEPTH (KM)	MAG	DIST (KM)	BACK AZ.	NO. STA
90	3	3	62	11	11	10.00							4
90	3	3	62	11	13	27.79	34.1367	117.6988	5.9	1.4	3.1	332	5
90	3	3	62	11	19	10.00							3
90	3	3	62	11	33	55.00							5
90	3	3	62	11	40	9.63	34.1535	117.6880	6.0		4.6	354	3
90	3	3	62	12	23	38.54	34.1365	117.7208	9.6	1.7	4.4	308	5
90	3	3	62	13	9	52.55	34.1295	117.7002	4.5	1.9	2.5	321	2
90	3	3	62	15	31	6.00							2
90	3	3	62	16	41	16.53	34.1302	117.6983	5.3	1.8	2.5	325	3
90	3	3	62	16	59	37.78	34.1205	117.7120	4.4	2.2	2.8	290	5
90	3	3	62	17	0	22.99	34.1172	117.7267	6.1	1.7	4.1	278	5
90	3	3	62	17	1	19.00							3
90	3	3	62	20	25	54.67	34.1268	117.7113	5.3	2.0	3.1	302	3
90	3	3	62	21	20	20.44	34.1295	117.7182	9.7	1.6	3.8	301	2
90	3	3	62	23	21	15.37	34.1157	117.6838	4.5	2.3	0.4	349	5
90	3	3	62	23	21	41.28	34.1142	117.6852	4.9	1.7	0.3	320	5
90	3	3	62	23	28	54.07	34.1152	117.6845	4.8	1.9	0.4	339	5
90	3	3	62	23	53	54.13	34.1307	117.6892	7.1		2.2	345	2
90	3	4	63	0	31	29.30	34.1308	117.6940	4.6	1.8	2.3	334	5
90	3	4	63	0	33	1.00							5
90	3	4	63	0	36	6.00							4
90	3	4	63	0	38	32.65	34.1232	117.6762	2.0		1.4	27	5
90	3	4	63	0	47	11.26	34.1298	117.6935	4.4	1.7	2.2	334	5
90	3	4	63	0	51	8.00							5
90	3	4	63	1	10	36.49	34.1120	117.7108	4.9	1.9	2.6	270	5
90	3	4	63	2	0	11.00							5
90	3	4	63	2	3	8.00							4
90	3	4	63	2	20	53.73	34.1308	117.7088	8.4	1.7	3.2	311	2
90	3	4	63	3	46	30.00							5
90	3	4	63	4	14	39.24	34.1467	117.7352	12.7	1.9	6.2	309	2
90	3	4	63	5	21	55.44	34.1360	117.7143	8.7	1.9	3.9	313	5
90	3	4	63	5	28	36.00							5
90	3	4	63	5	34	25.00							5
90	3	4	63	5	41	40.16	34.1522	117.7102	11.2	2.2	5.1	331	5
90	3	4	63	5	44	54.00							5
90	3	4	63	6	30	24.91	34.1232	117.7038	4.5	2.0	2.3	303	5
90	3	4	63	6	47	51.00							5
90	3	4	63	7	9	38.00							3
90	3	4	63	7	34	1.40	34.1410	117.6880	10.1	1.5	3.3	352	5
90	3	4	63	8	0	51.00							2
90	3	4	63	8	4	24.00							4
90	3	4	63	8	24	4.00							4
90	3	4	63	8	27	21.42	34.1225	117.6968	5.0	1.6	1.7	313	5
90	3	4	63	8	31	57.12	34.1417	117.7135	4.8	1.6	4.3	320	5
90	3	4	63	8	40	52.00							5
90	3	4	63	9	4	23.46	34.1215	117.6982	4.1	2.2	1.8	307	5
90	3	4	63	9	10	3.00							4
90	3	4	63	9	31	55.00							4
90	3	4	63	10	18	38.00							2
90	3	4	63	10	23	33.00							2

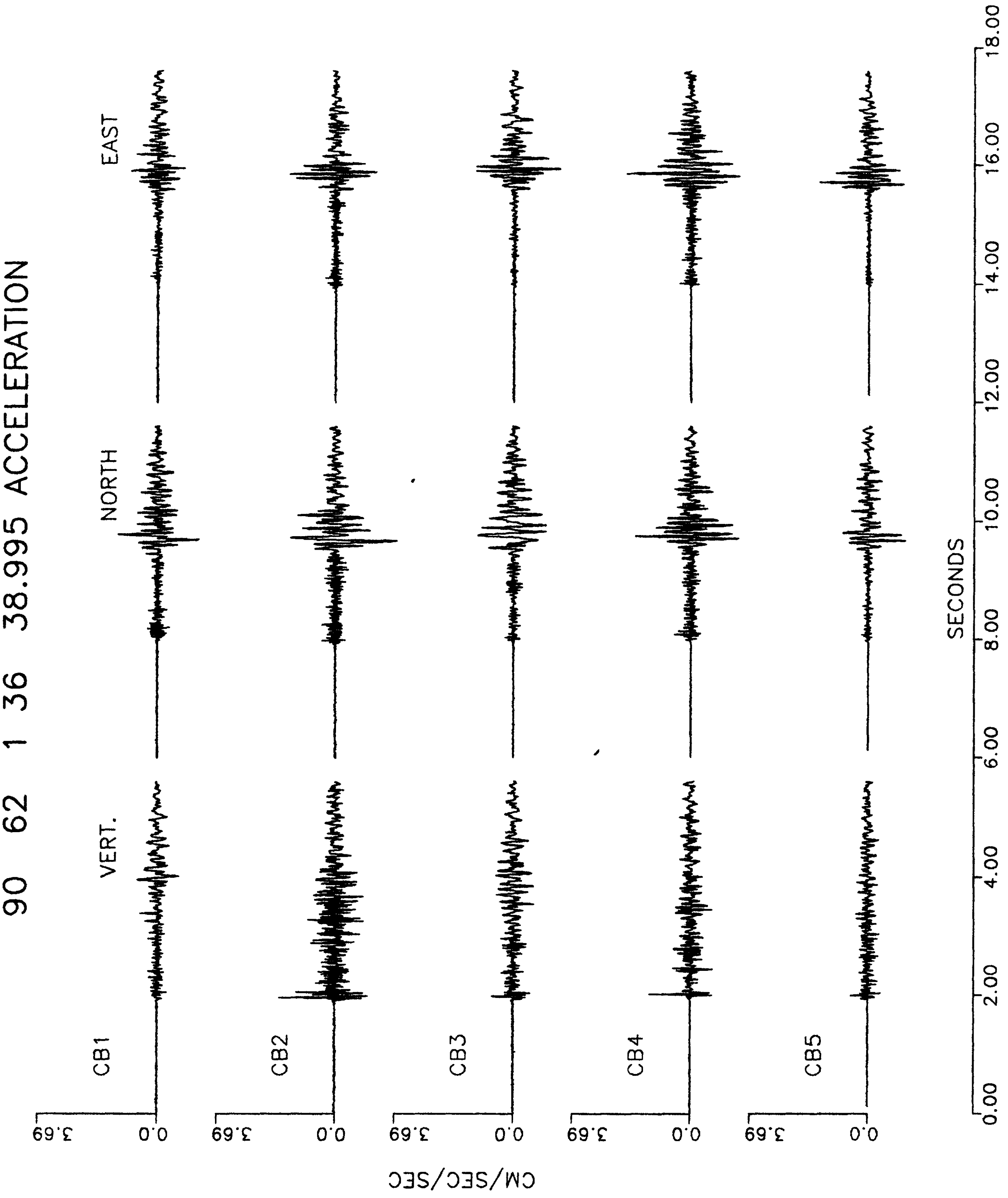
YR	MO	DAY	JULIAN DAY	HR	MIN	SEC	LAT (N)	LONG (W)	DEPTH (KM)	MAG	DIST (KM)	BACK AZ.	NO. STA
90	3	4	63	10	23	54.03	34.1547	117.7068	11.7	1.9	5.2	335	5
90	3	4	63	10	53	53.32	34.1398	117.6945	10.1		3.3	341	5
90	3	4	63	10	58	7.00							4
90	3	4	63	11	15	59.00							5
90	3	4	63	11	17	10.00							3
90	3	4	63	11	47	58.00							2
90	3	4	63	11	53	34.58	34.1373	117.7182	5.4	1.6	4.3	311	4
90	3	4	63	11	53	56.57	34.1330	117.7053	4.3	1.4	3.1	319	4
90	3	4	63	11	55	27.00							4
90	3	4	63	12	5	5.90	34.1158	117.7200	4.7	1.7	3.4	277	4
90	3	4	63	12	20	28.63	34.1328	117.7078	4.7	1.8	3.3	315	4
90	3	4	63	12	33	45.28	34.1782	117.6830	6.9	1.9	7.4	0	4
90	3	4	63	12	39	15.00							3
90	3	4	63	12	40	43.00							3
90	3	4	63	12	48	21.00							4
90	3	4	63	13	12	41.00							4
90	3	4	63	13	17	44.00							2
90	3	4	63	13	19	42.90	34.1188	117.7227	7.2	1.7	3.7	282	4
90	3	4	63	13	37	27.90	34.1113	117.7267	4.1	1.4	4.0	269	4
90	3	4	63	13	38	36.00							3
90	3	4	63	13	40	7.86	34.1130	117.6833	4.6	2.0	0.1	344	4
90	3	4	63	13	43	10.80	34.1210	117.6810	8.2		1.0	10	4
90	3	4	63	13	46	20.00							2
90	3	4	63	14	0	3.15	34.1147	117.6802	4.7	1.9	0.4	41	4
90	3	4	63	14	4	0.00							3
90	3	4	63	14	6	42.37	34.1090	117.6860	4.8	1.5	0.4	220	3
90	3	4	63	14	32	40.00							3
90	3	4	63	14	36	31.33	34.1540	117.6970	10.6	1.8	4.8	345	2
90	3	4	63	14	44	36.75	34.1012	117.6968	4.5	1.7	1.8	227	2
90	3	4	63	15	2	41.00							2
90	3	4	63	15	7	42.78	34.1127	117.6827	4.1	2.7	0.1	23	2
90	3	4	63	15	10	21.00							2
90	3	4	63	15	11	8.00							2
90	3	4	63	15	12	59.00							2
90	3	4	63	15	14	30.00							2
90	3	4	63	15	14	56.57	34.1095	117.6825	4.4	1.6	0.3	171	2
90	3	4	63	15	15	22.80	34.1132	117.6757	4.2	1.3	0.7	79	2
90	3	4	63	15	20	50.00							2
90	3	4	63	15	23	44.00							2
90	3	4	63	15	45	47.46	34.1780	117.6842	6.8	1.8	7.3	359	2
90	3	4	63	15	49	37.34	34.1083	117.6928	5.0	1.6	1.0	246	2
90	3	4	63	15	51	4.00							2
90	3	4	63	16	10	26.69	34.1635	117.6658	9.5		5.9	15	2
90	3	4	63	16	25	15.27	34.1123	117.6815	4.2	2.4	0.1	75	2
90	3	4	63	16	26	38.00							2
90	3	4	63	16	27	2.00							2
90	3	4	63	16	39	41.11	34.1097	117.6842	4.8	1.8	0.3	202	1
90	3	4	63	16	45	15.76	34.1158	117.6838	4.1	3.3	0.4	350	1
90	3	4	63	17	25	52.00							2
90	3	4	63	17	33	28.92	34.1557	117.7040	11.2	1.8	5.2	338	2

YR	MO	DAY	JULIAN DAY	HR	MIN	SEC	LAT (N)	LONG (W)	DEPTH (KM)	MAG	DIST (KM)	BACK AZ.	NO. STA
90	3	4	63	17	36	25.53	34.1067	117.6893	6.4	1.7	0.8	225	4
90	3	4	63	17	49	25.74	34.1393	117.6518	8.4	1.4	4.2	43	5
90	3	4	63	17	54	32.00							2
90	3	4	63	17	58	58.74	34.1190	117.6983	5.3	1.6	1.6	299	5
90	3	4	63	18	4	7.94	34.1248	117.7203	6.0	1.9	3.7	293	2
90	3	4	63	18	18	11.00							2
90	3	4	63	19	5	50.11	34.1778	117.6807	6.6	1.8	7.3	2	3
90	3	4	63	20	22	22.84	34.1393	117.6927	5.0	2.0	3.2	344	5
90	3	4	63	23	16	9.98	34.1235	117.6982	4.4	1.7	1.9	313	5
90	3	4	63	23	35	13.43	34.1467	117.6743	6.0	1.5	3.9	12	4
90	3	5	64	0	31	28.00							3
90	3	5	64	0	49	43.04	34.1348	117.7048	4.2	1.9	3.2	322	5
90	3	5	64	3	15	5.38	34.1325	117.7127	5.0		3.6	310	2
90	3	5	64	4	15	10.63	34.1398	117.7008	5.9	1.7	3.5	332	5
90	3	5	64	4	35	41.83	34.1402	117.7152	6.0	1.8	4.3	317	3
90	3	5	64	5	35	55.28	34.1233	117.7215	8.4	2.0	3.8	290	5
90	3	5	64	5	55	26.36	34.1113	117.6920	4.8	1.9	0.8	265	5
90	3	5	64	5	55	47.00							2
90	3	5	64	6	28	13.00							2
90	3	5	64	7	6	4.63	34.1363	117.6905	5.4	1.8	2.8	346	4
90	3	5	64	7	27	0.00							3
90	3	5	64	8	22	8.00							3
90	3	5	64	8	53	28.30	34.1438	117.7210	6.9	1.8	5.0	315	2
90	3	5	64	8	58	6.15	34.1415	117.6687	4.7	1.6	3.5	22	5
90	3	5	64	9	19	56.28	34.1297	117.6823	3.0	1.5	2.0	2	2
90	3	5	64	10	54	50.37	34.1250	117.7180	7.9	2.1	3.5	294	5
90	3	5	64	12	12	57.44	34.1388	117.7272	5.9	1.9	5.0	306	5
90	3	5	64	12	19	8.16	34.1153	117.6858	4.5	1.9	0.5	325	5
90	3	5	64	12	19	53.00							5
90	3	5	64	12	29	48.00							2
90	3	5	64	12	32	30.00							2
90	3	5	64	12	55	44.42	34.1175	117.6920	6.2	1.6	1.0	306	5
90	3	5	64	14	0	19.27	34.1113	117.6975	7.7		1.3	267	3
90	3	5	64	19	28	47.32	34.1325	117.6943	4.7	2.3	2.5	335	5
90	3	5	64	19	46	40.00							3
90	3	6	65	2	22	39.07	34.1320	117.7178	7.4	1.7	3.9	305	2
90	3	6	65	8	22	32.42	34.1403	117.7287	5.4	1.5	5.3	307	2
90	3	6	65	9	20	40.04	34.1225	117.7382	8.1	1.4	5.2	283	4
90	3	6	65	18	1	49.15	34.1557	117.6993	9.8		5.1	343	4
90	3	7	66	3	18	57.35	34.1125	117.6837	4.8	2.0	0.1	312	5
90	3	7	66	3	27	37.48	34.1120	117.6853	4.9	1.4	0.2	270	2
90	3	7	66	6	9	50.78	34.1215	117.7050	5.2	1.4	2.3	298	4
90	3	7	66	9	21	7.67	34.1467	117.7078	12.6	1.7	4.5	329	2
90	3	7	66	10	38	57.43	34.1310	117.6938	5.1	1.6	2.3	335	3
90	3	7	66	10	50	18.15	34.1475	117.6898	8.3	1.5	4.0	351	3
90	3	7	66	11	1	4.01	34.1117	117.6823	4.9	1.2	0.1	121	5
90	3	7	66	11	16	47.27	34.1203	117.7208	5.3	1.4	3.6	285	5
90	3	7	66	11	35	56.19	34.1250	117.6785	4.9	1.3	1.5	16	5
90	3	8	67	5	39	27.65	34.1175	117.7142	4.9	1.3	2.9	282	4
90	3	8	67	6	25	17.97	34.1312	117.7182	8.4	3.4	3.9	303	4

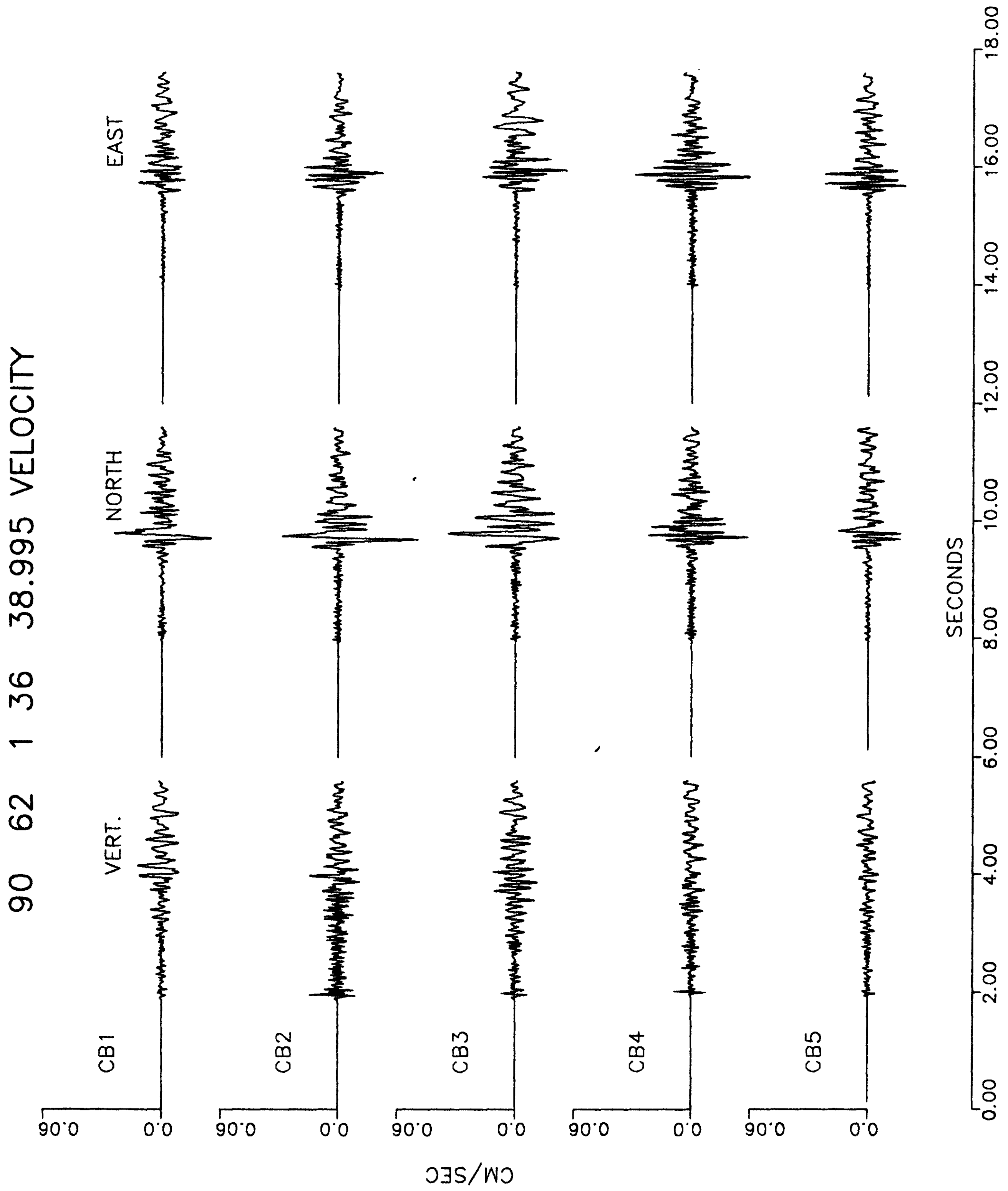
YR	MO	DAY	JULIAN DAY	HR	MIN	SEC	LAT (N)	LONG (W)	DEPTH (KM)	MAG	DIST (KM)	BACK AZ.	NO. STA
90	3	8	67	8	2	34.36	34.1415	117.7133	4.4	1.3	4.3	320	4
90	3	8	67	22	43	52.48	34.1402	117.6943	5.3	1.9	3.3	342	2
90	3	9	68	1	19	19.92	34.1383	117.7288	5.3	1.8	5.1	305	4
90	3	9	68	5	39	0.71	34.1325	117.7108	4.8	1.9	3.4	312	4
90	3	9	68	9	5	39.09	34.1411	117.7132	5.1	1.4	4.3	319	2
90	3	9	68	11	31	6.04	34.1480	117.7058	5.3	1.6	4.5	332	4
90	3	10	69	0	33	3.23	34.1487	117.7397	4.5	1.9	6.6	308	2
90	3	10	69	4	11	55.62	34.1808	117.6833	6.9	2.2	7.7	360	2
90	3	10	69	8	36	19.79	34.1255	117.6662	5.0	1.2	2.2	46	3
90	3	10	69	9	10	30.94	34.1425	117.7168	4.8	1.5	4.6	317	1
90	3	10	69	17	45	44.52	34.1210	117.7073	4.5	2.1	2.5	294	2
90	3	10	69	19	4	17.76	34.1208	117.7075	4.5	2.1	2.5	294	3
90	3	10	69	19	18	11.16	34.1205	117.7078	4.5	2.1	2.5	293	4
90	3	10	69	20	54	1.27	34.1208	117.7073	4.0	2.2	2.5	294	4
90	3	10	69	21	19	49.48	34.1207	117.7090	4.5	1.9	2.6	292	4
90	3	11	70	1	12	25.96	34.1165	117.7208	4.4	1.6	3.5	278	1
90	3	11	70	2	5	33.05	34.1215	117.7052	4.8	1.4	2.3	297	3
90	3	11	70	2	25	4.18	34.1162	117.6825	4.8	1.7	0.5	6	4
90	3	11	70	3	37	15.55	34.1438	117.6718	5.2		3.7	16	1
90	3	11	70	4	53	17.53	34.1138	117.7195	5.2	1.4	3.4	274	2
90	3	11	70	6	37	50.97	34.1192	117.7133	6.7	1.2	2.9	286	2
90	3	11	70	10	33	44.87	34.1260	117.7003	8.3	2.1	2.2	314	2
90	3	12	71	0	11	46.39	34.1213	117.7198	5.3		3.6	287	1
90	3	12	71	9	4	6.01	34.1288	117.6977	4.1	2.3	2.3	324	3
90	3	12	71	9	39	5.23	34.1240	117.7212	5.2	1.3	3.8	291	1
90	3	12	71	11	26	10.99	34.1267	117.6995	4.5	3.1	2.2	317	3
90	3	12	71	11	29	36.20	34.1262	117.7000	3.9	2.8	2.2	315	3
90	3	12	71	11	33	6.00							2
90	3	12	71	11	37	20.00							2
90	3	12	71	23	22	53.00							1
90	3	13	72	7	10	56.54	34.1188	117.7233	4.6	2.5	3.8	282	3
90	3	13	72	9	9	43.55	34.1483	117.7100	4.4	1.7	4.7	328	2
90	3	14	73	10	30	34.98	34.1502	117.7107	5.2	1.9	5.0	329	3
90	3	15	74	1	10	23.31	34.1283	117.7090	5.6	2.1	3.0	307	3
90	3	15	74	4	56	15.08	34.1225	117.7115	5.2	1.7	2.9	294	3
90	3	15	74	8	39	54.47	34.1165	117.7272	4.8	1.7	4.1	277	3
90	3	15	74	9	14	12.00							3
90	3	18	77	13	56	38.11	34.1458	117.7108	8.7	3.1	4.6	326	3
90	3	19	78	9	10	23.25	34.1300	117.7178	8.8	2.1	3.8	302	3
90	3	20	79	4	59	27.06	34.1832	117.6813	7.2	2.0	7.9	1	2
90	3	20	79	9	23	3.88	34.1322	117.7030	4.9	1.7	2.9	321	3

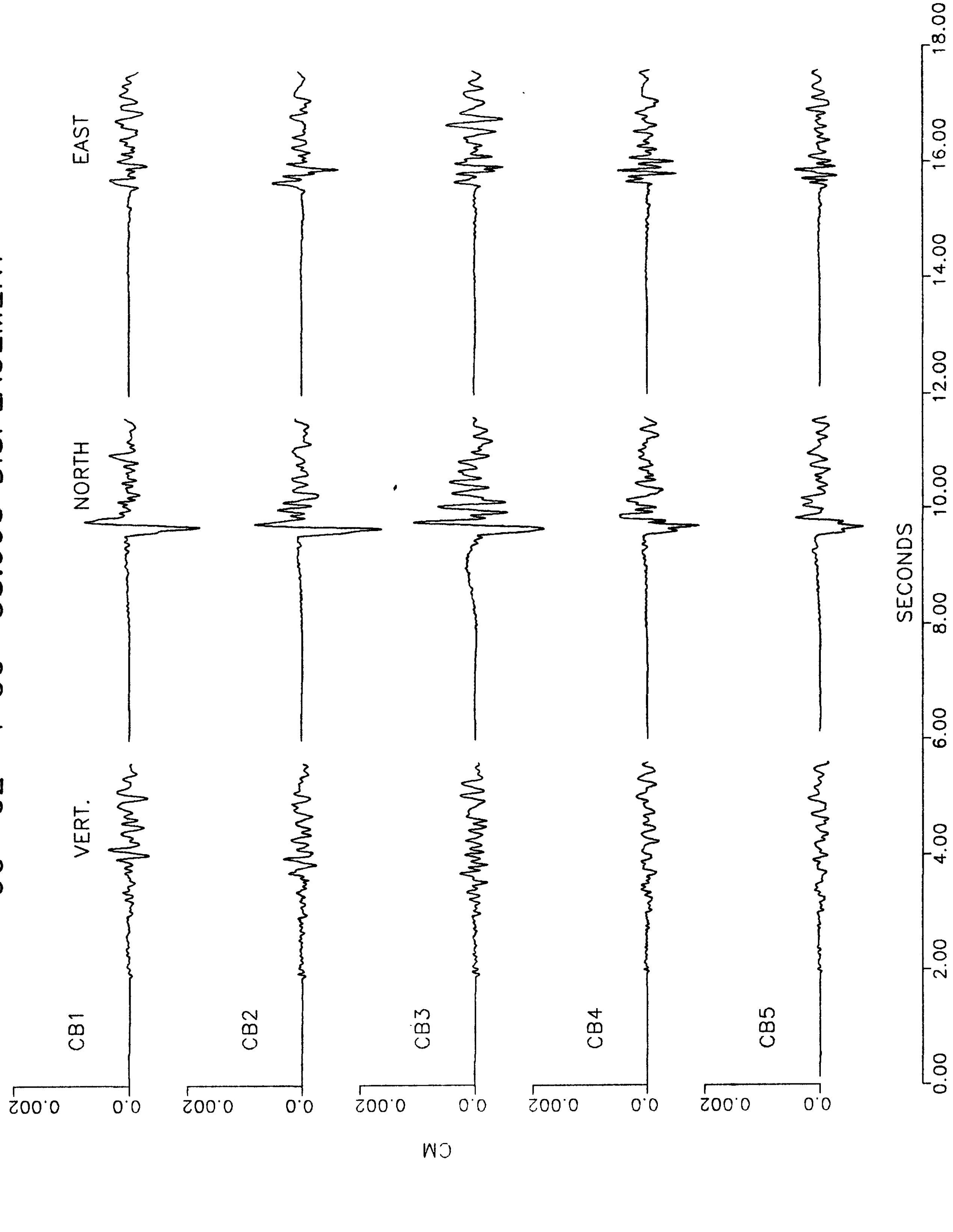
Appendix 2. EXAMPLES OF WAVEFORM DATA

The following pages show the three-component acceleration, velocity and displacement data from 11 events recorded at the Cable Airport Array. The displacement data were derived from the velocity components and filtered using a high-pass Butterworth filter with a corner at 0.4 hz. The trigger time of the upper most station on each page, is given in the title (year, julian day, hour, minute and second). All the traces on each page are plotted at the same amplitude scale.

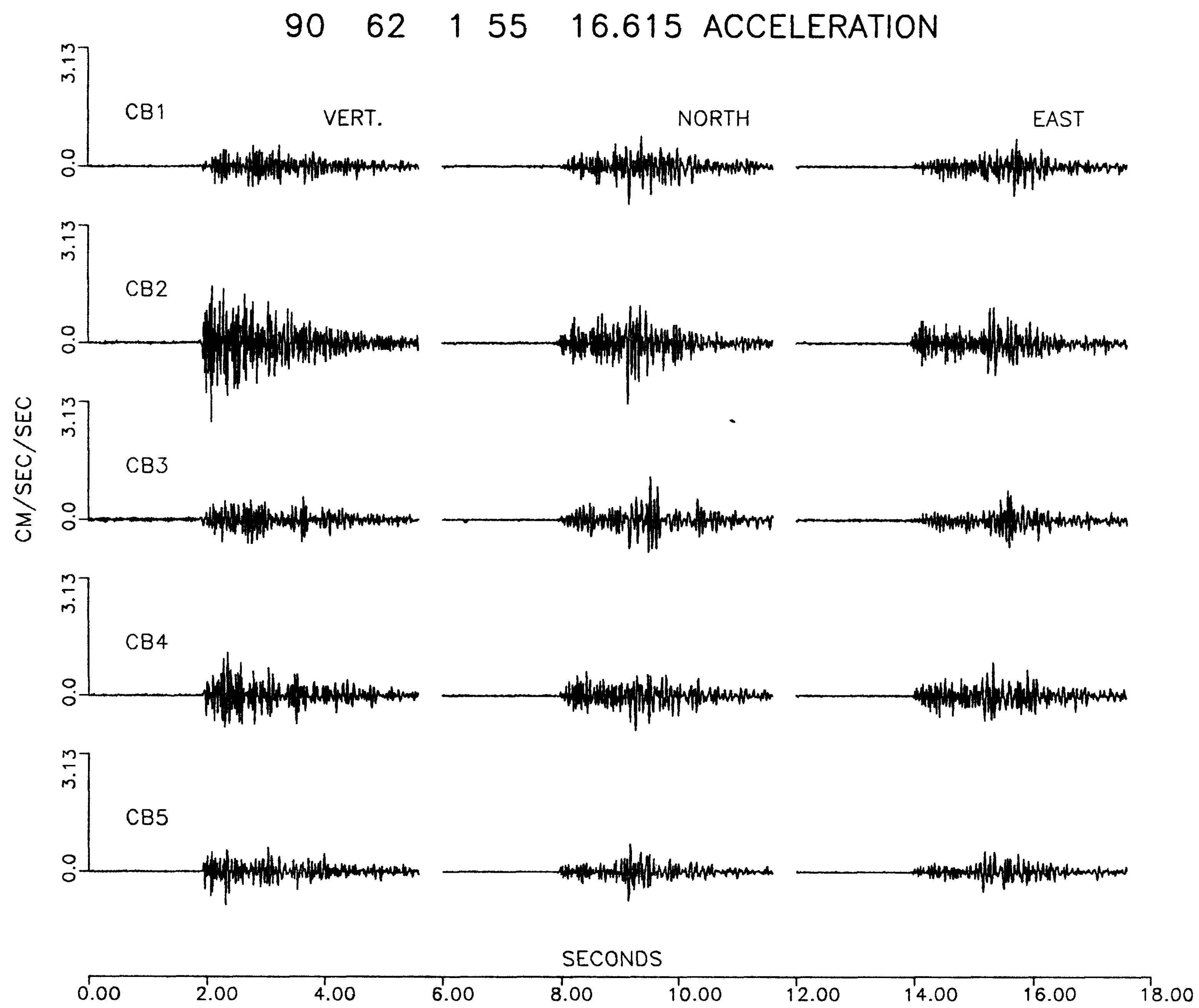


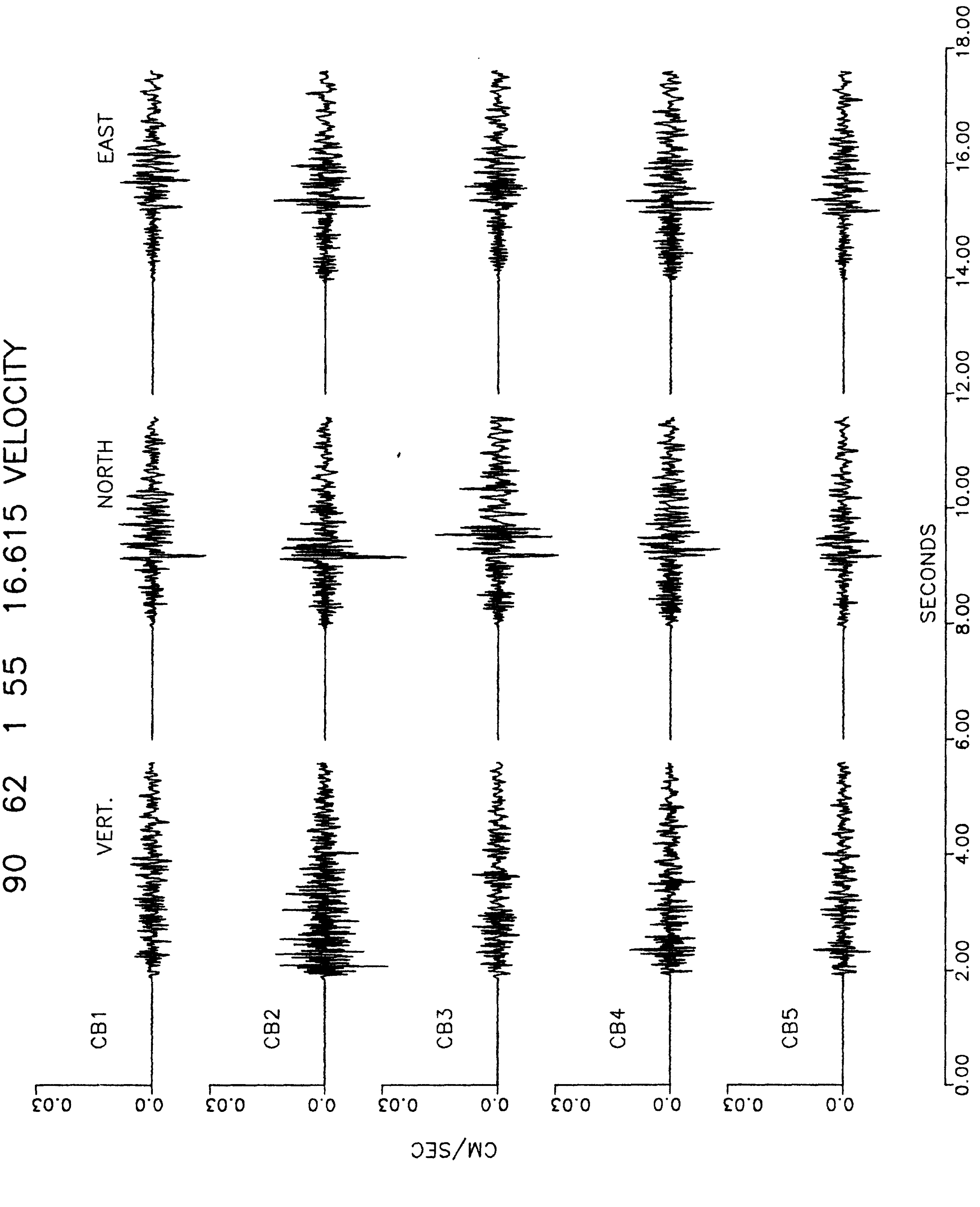
90 62 1 36 38.995 ACCELERATION
VERT.
NORTH
EAST
CB1
CB2
CB3
CB4
CB5
3.69
0.0
CM/SEC/SEC
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
SECONDS

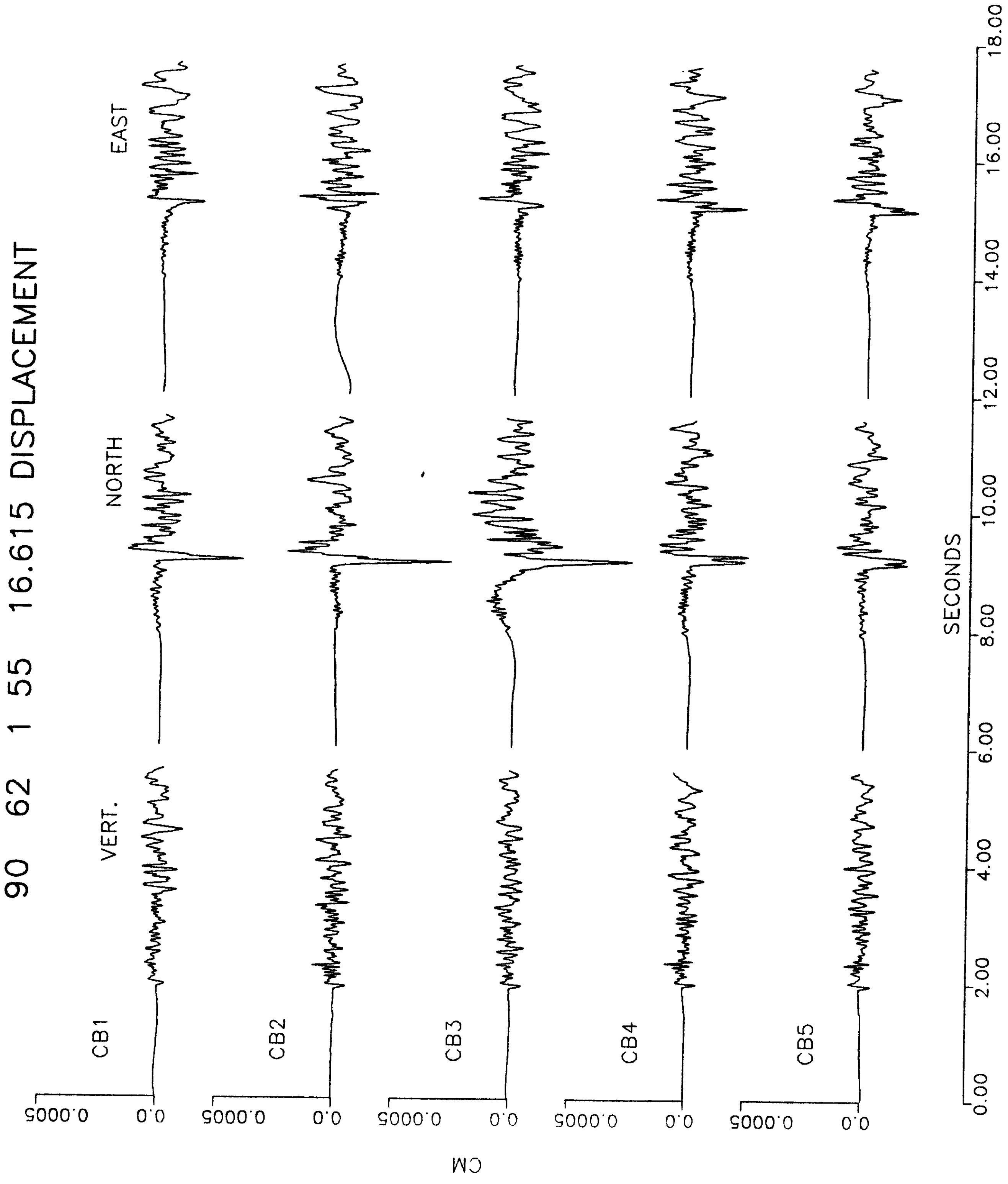

90 62 1 36 38.995 VELOCITY
VERT.
NORTH
EAST
CB1
CB2
CB3
CB4
CB5
0.06
0.0
CM/SEC
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
SECONDS

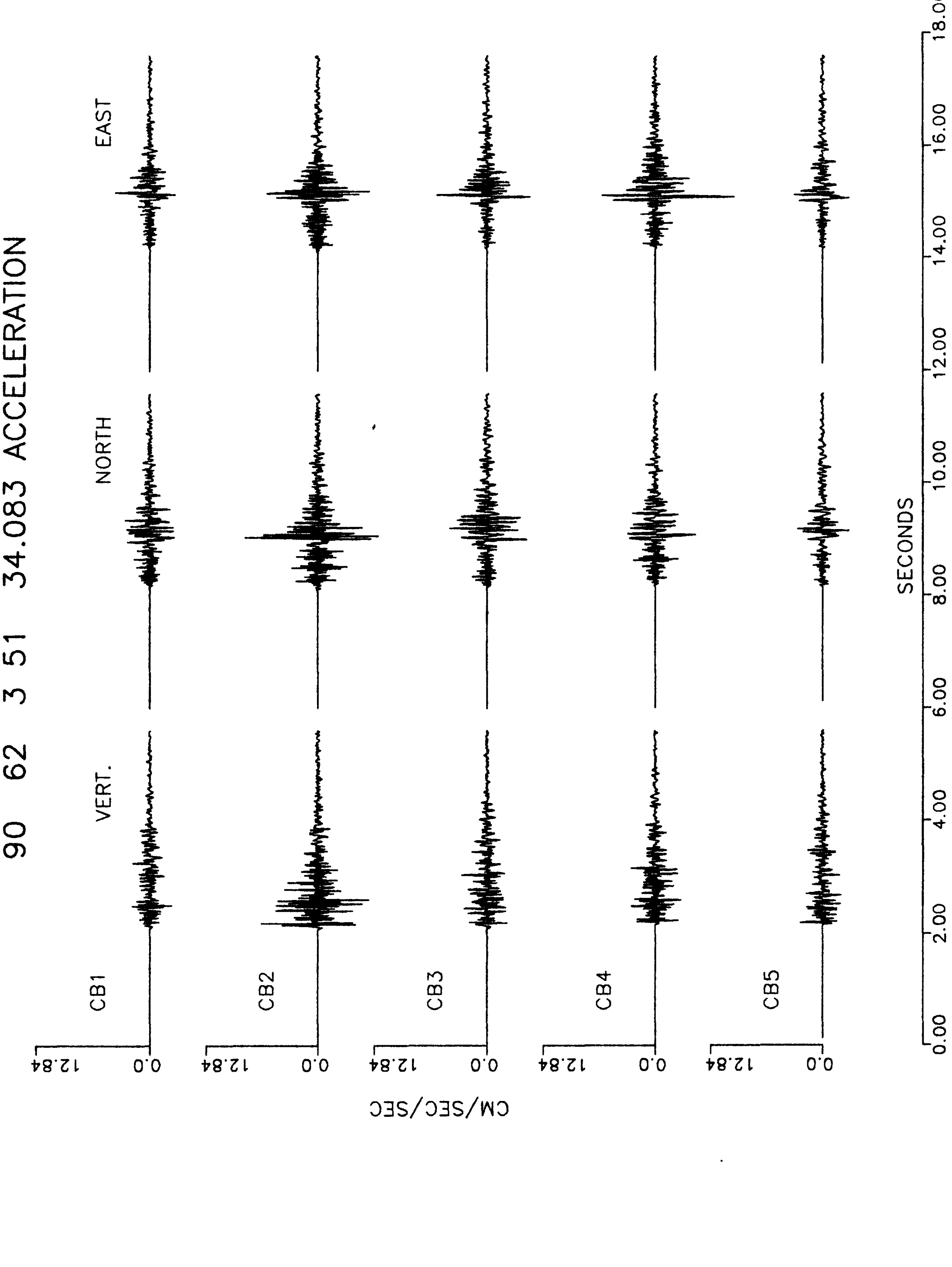


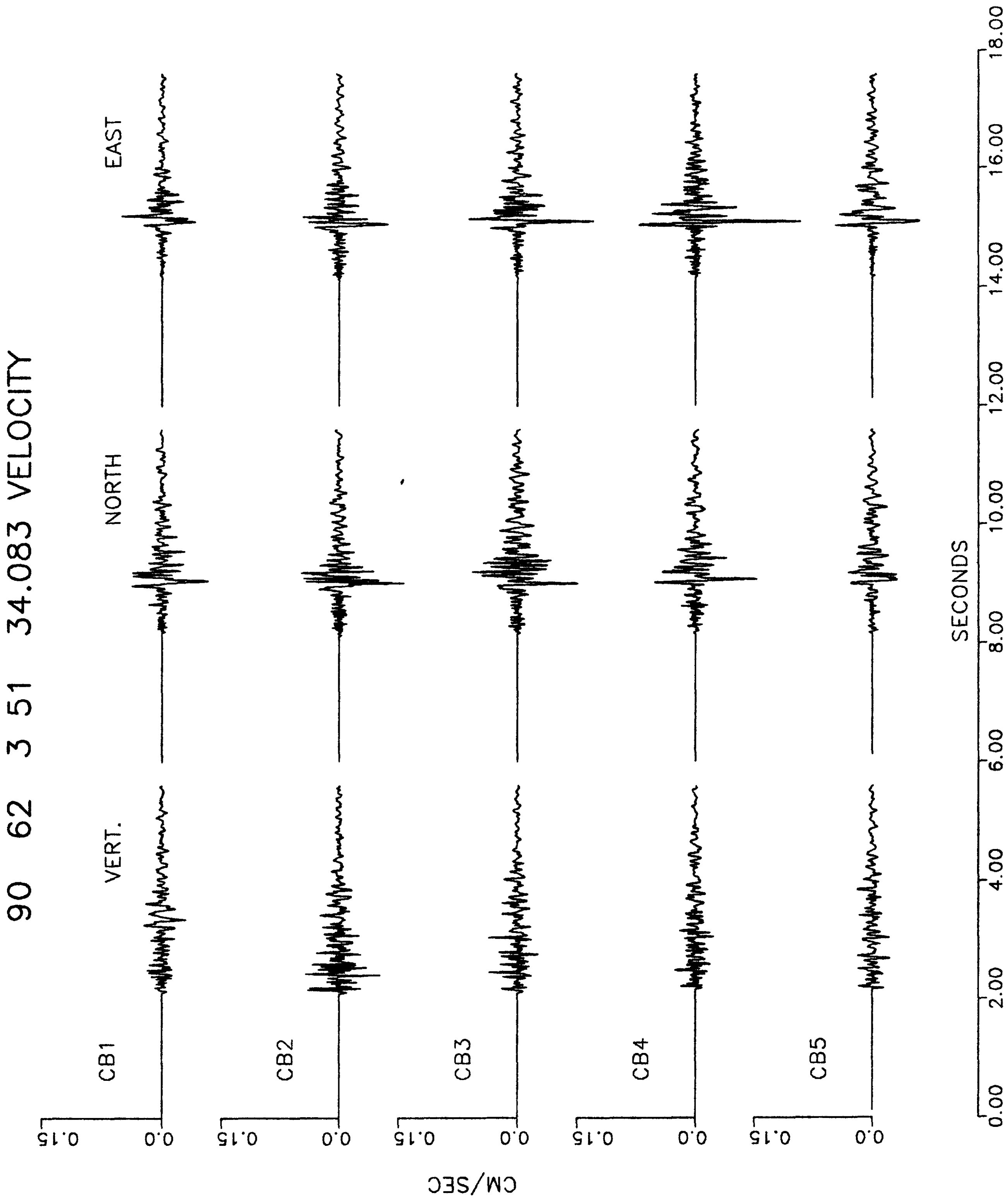
90 62 1 36 38.995 DISPLACEMENT
VERT.
NORTH
EAST
CB1
CB2
CB3
CB4
CB5
0.0
0.002
CM
SECONDS
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00


90 62 1 55 16.615 ACCELERATION
VERT.
NORTH
EAST
CB1
CB2
CB3
CB4
CB5
3.13
0.0
CM/SEC/SEC
SECONDS
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00

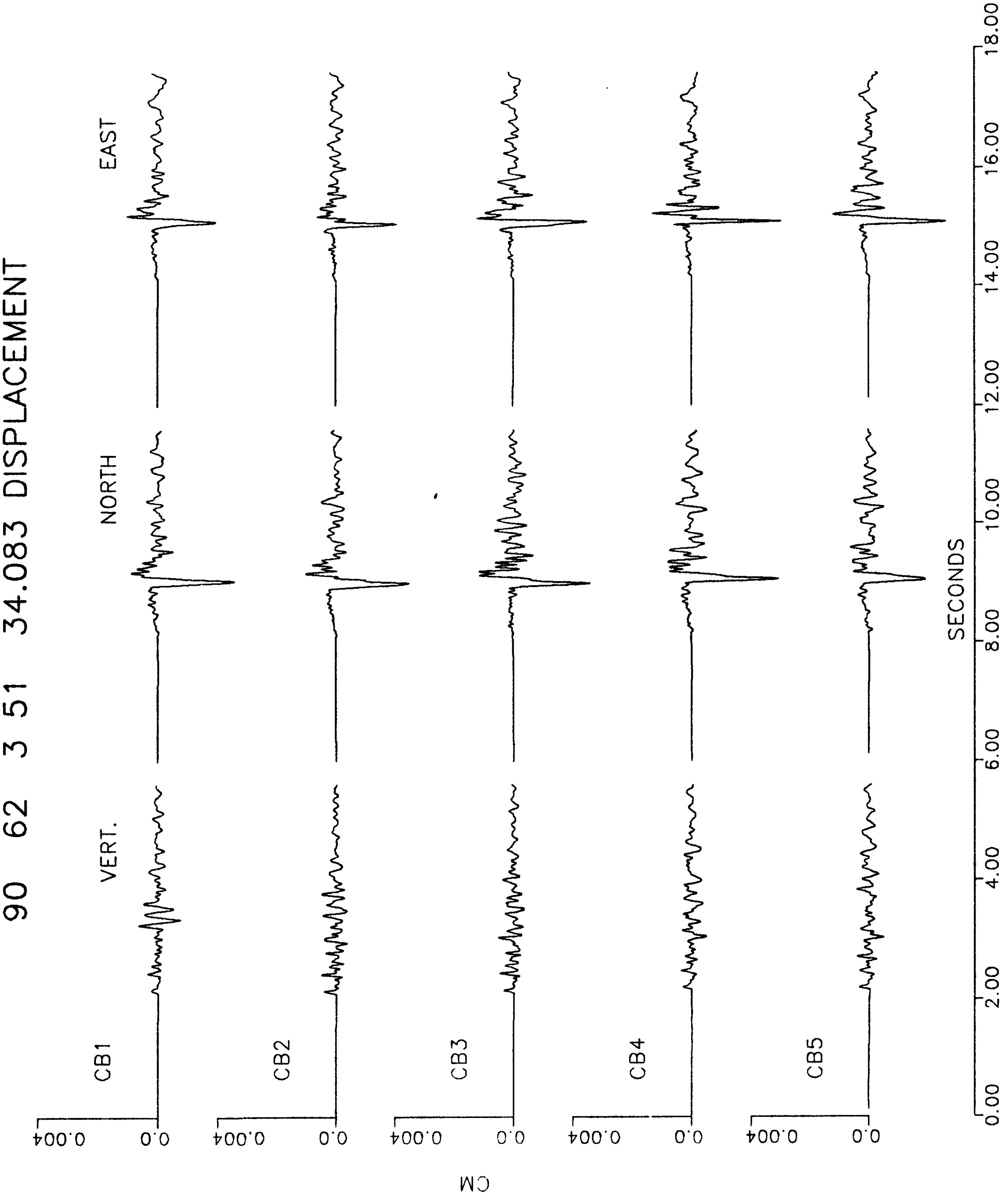

90 62 1 55 16.615 VELOCITY
VERT.
NORTH
EAST
CB1
CB2
CB3
CB4
CB5
0.03
0.0
CM/SEC
SECONDS
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00

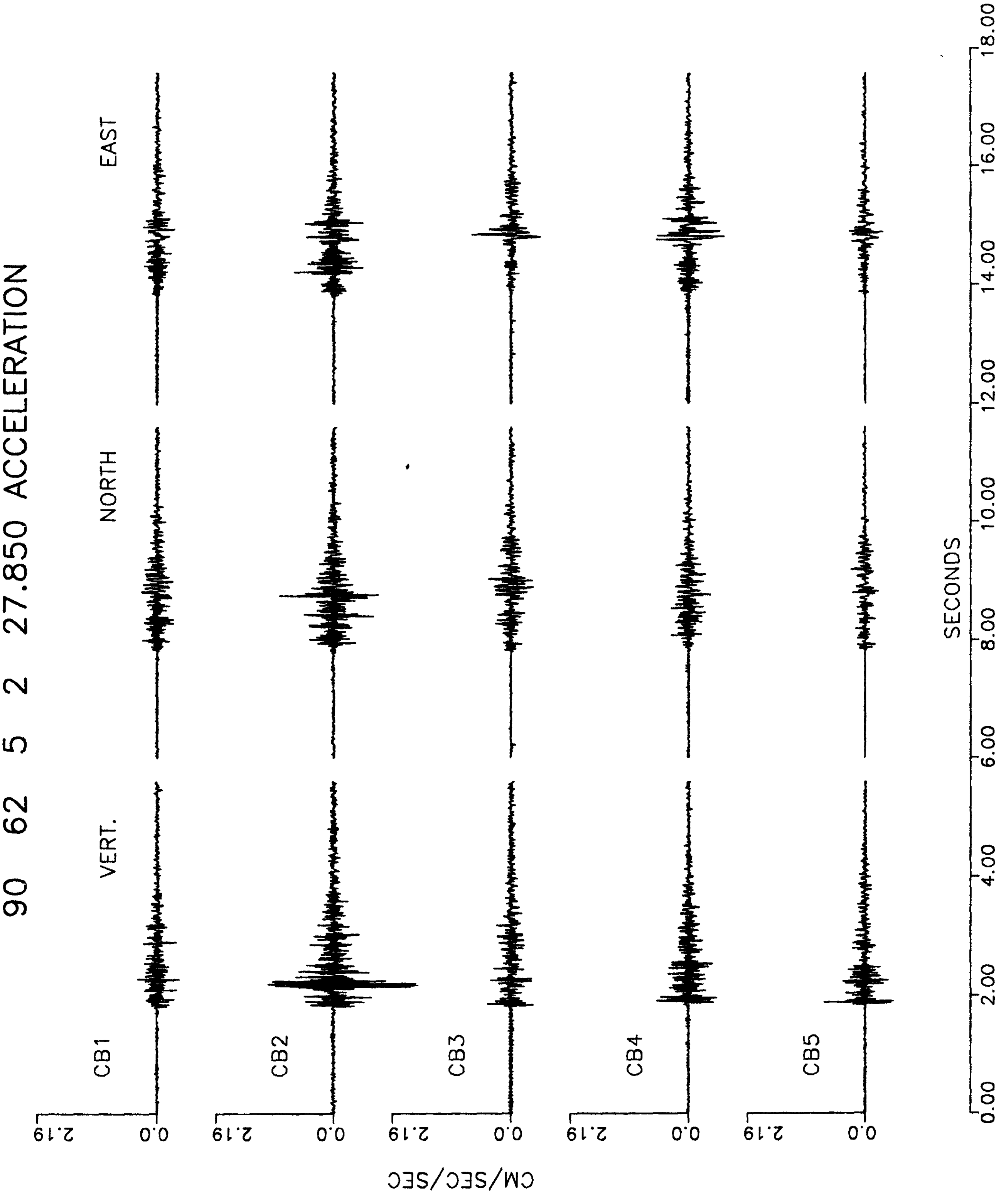

90 62 1 55 16.615 DISPLACEMENT
VERT.
NORTH
EAST
CB1
CB2
CB3
CB4
CB5
0.0
0.0005
CM
SECONDS
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00

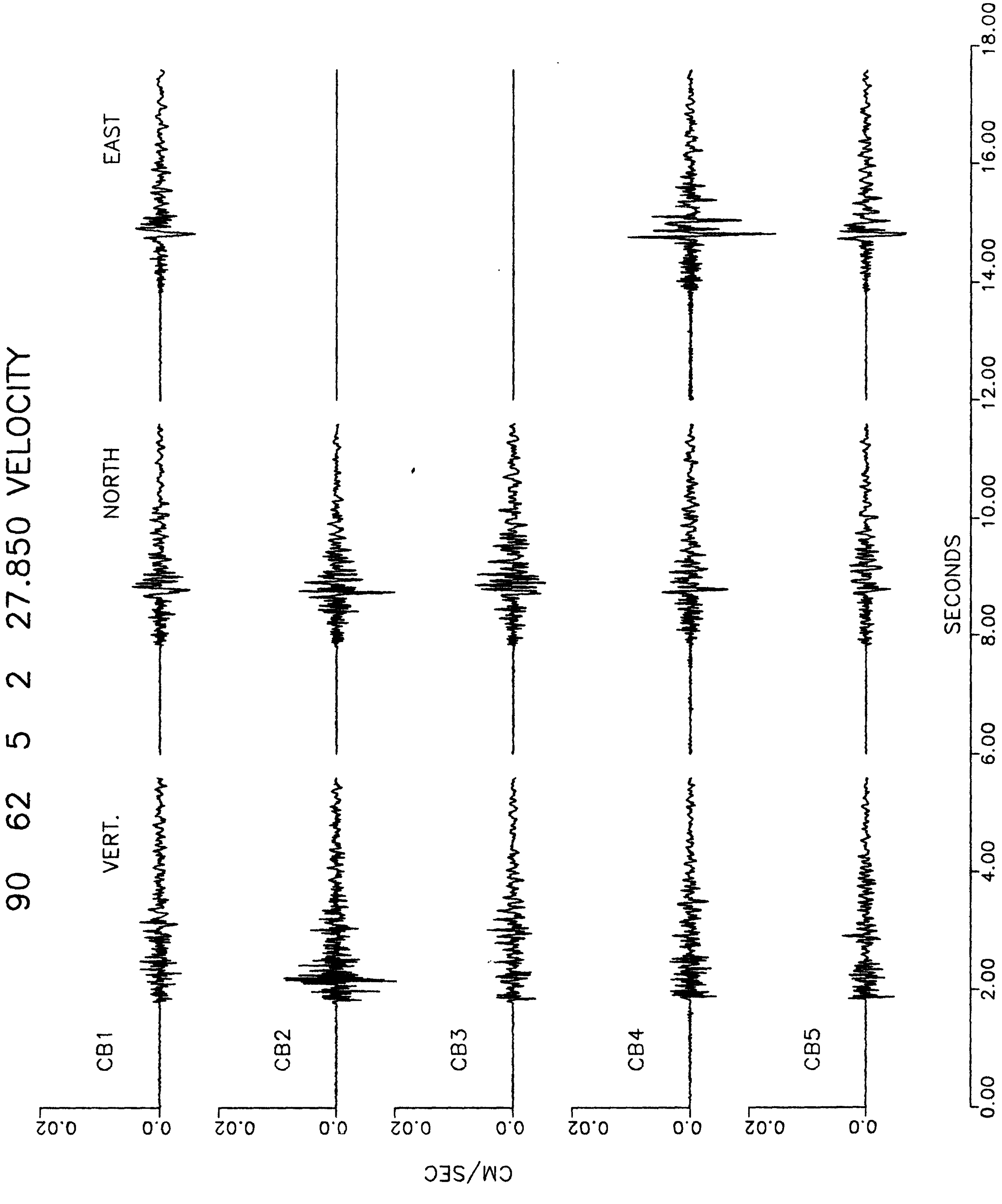

90 62 3 51 34.083 ACCELERATION
VERT.
NORTH
EAST
CB1
CB2
CB3
CB4
CB5
12.84
0.0
CM/SEC/SEC
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
SECONDS



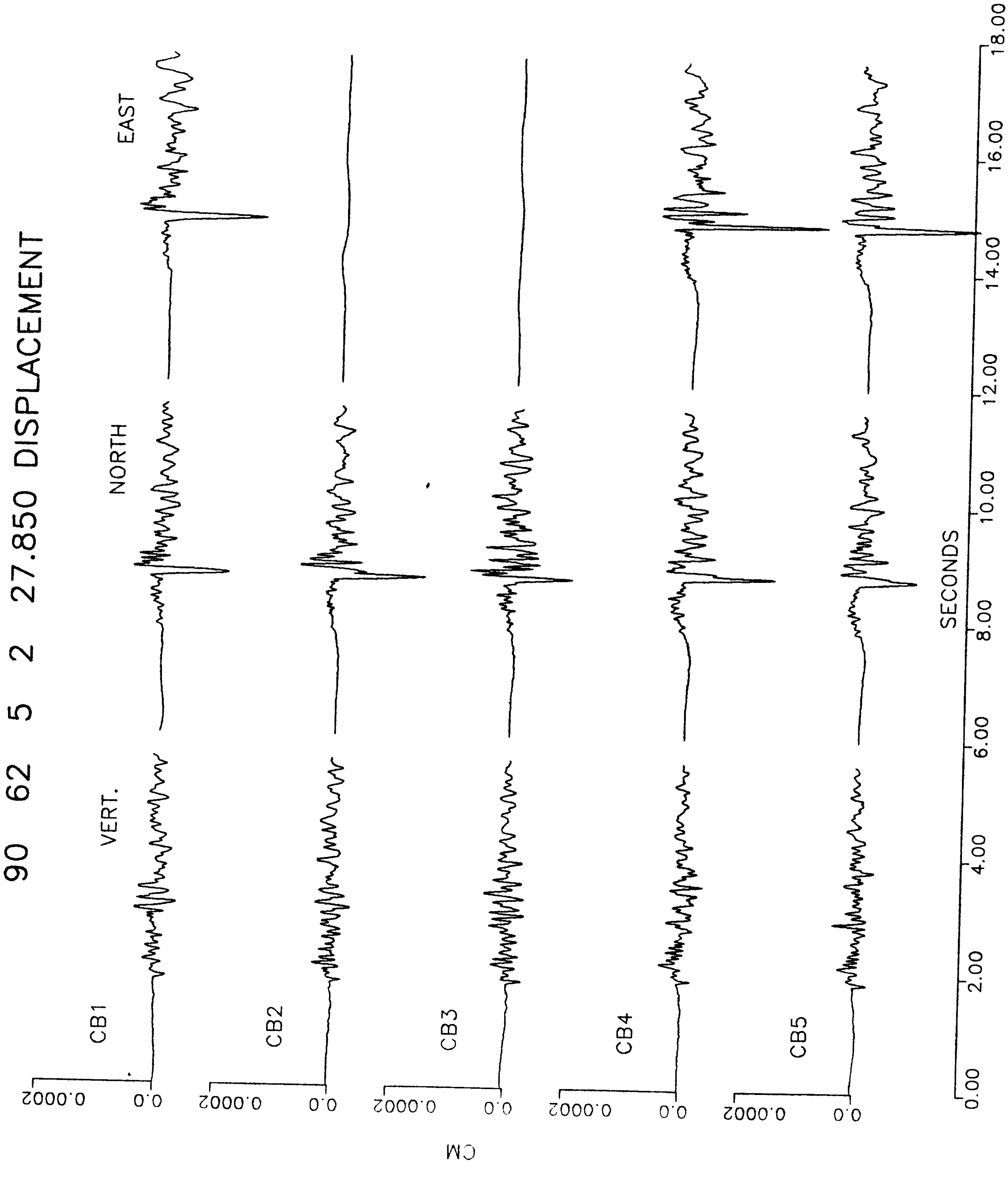
90 62 3 51 34.083 VELOCITY
VERT.
NORTH
EAST
CB1
CB2
CB3
CB4
CB5
0.15
0.0
CM/SEC
SECONDS
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00

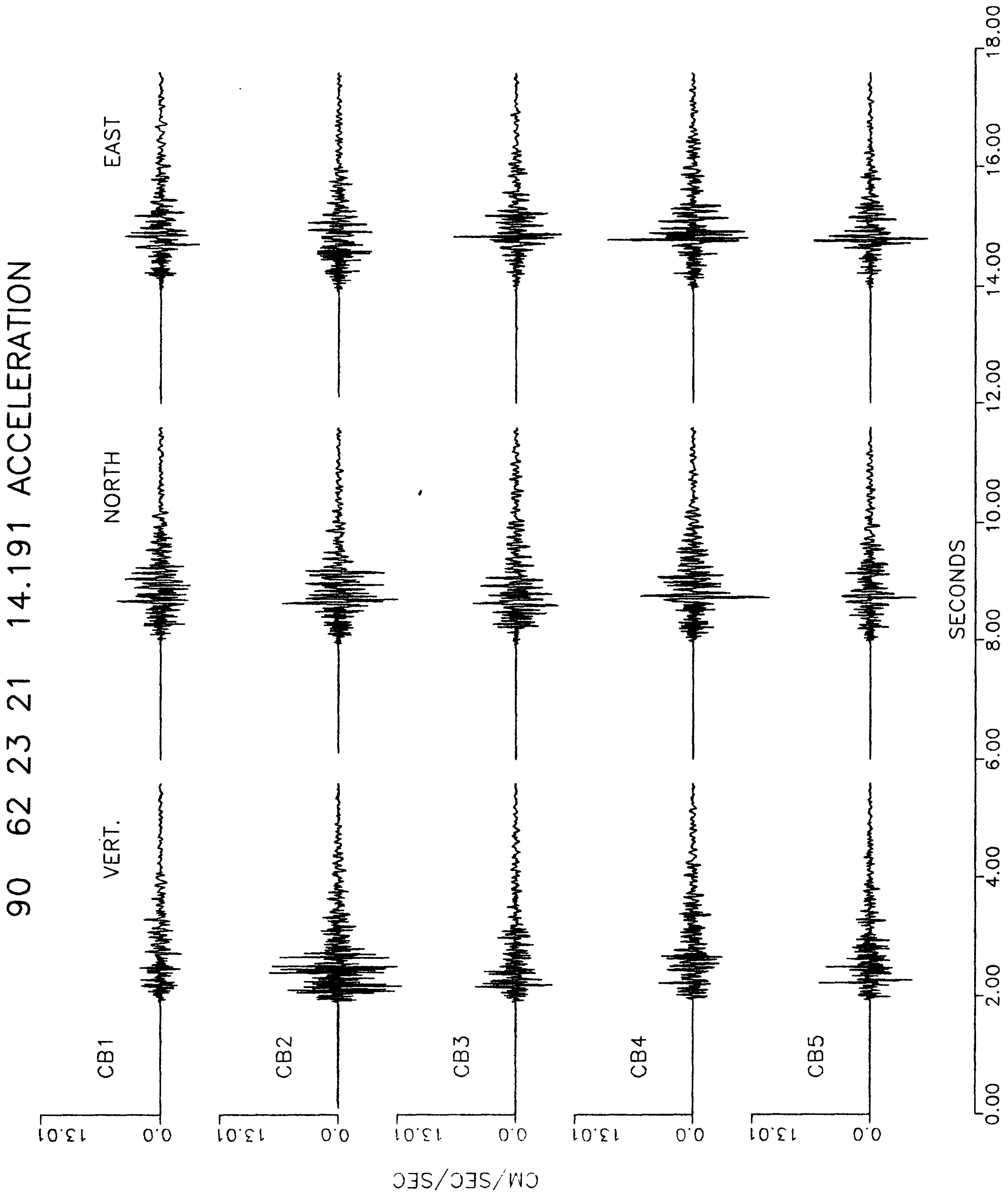

90 62 3 51 34.083 DISPLACEMENT
VERT.
NORTH
EAST
CB1
CB2
CB3
CB4
CB5
0.004
0.0
CM
SECONDS
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00

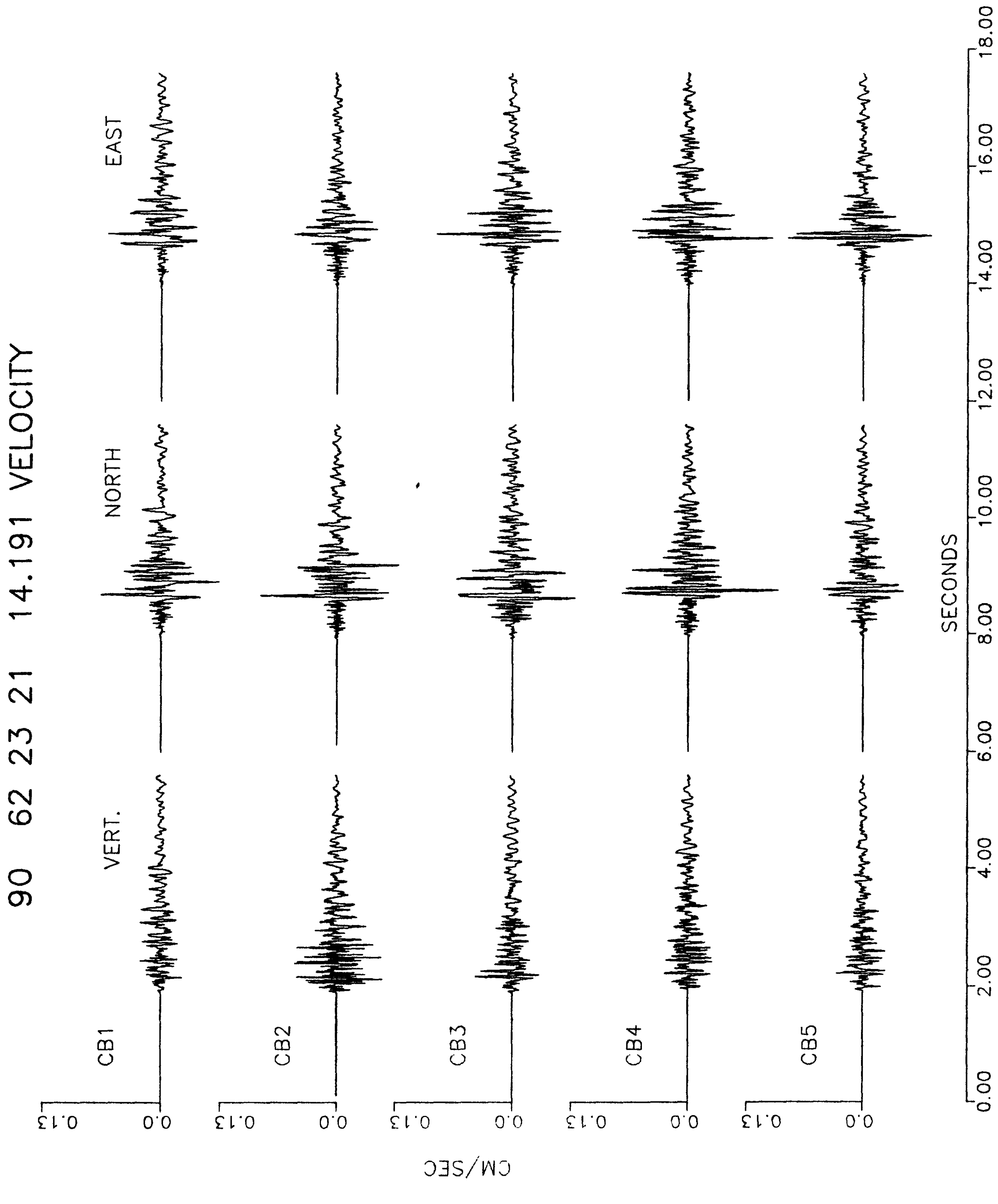

90 62 5 2 27.850 ACCELERATION
VERT.
NORTH
EAST
CB1
CB2
CB3
CB4
CB5
2.19
0.0
CM/SEC/SEC
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
SECONDS



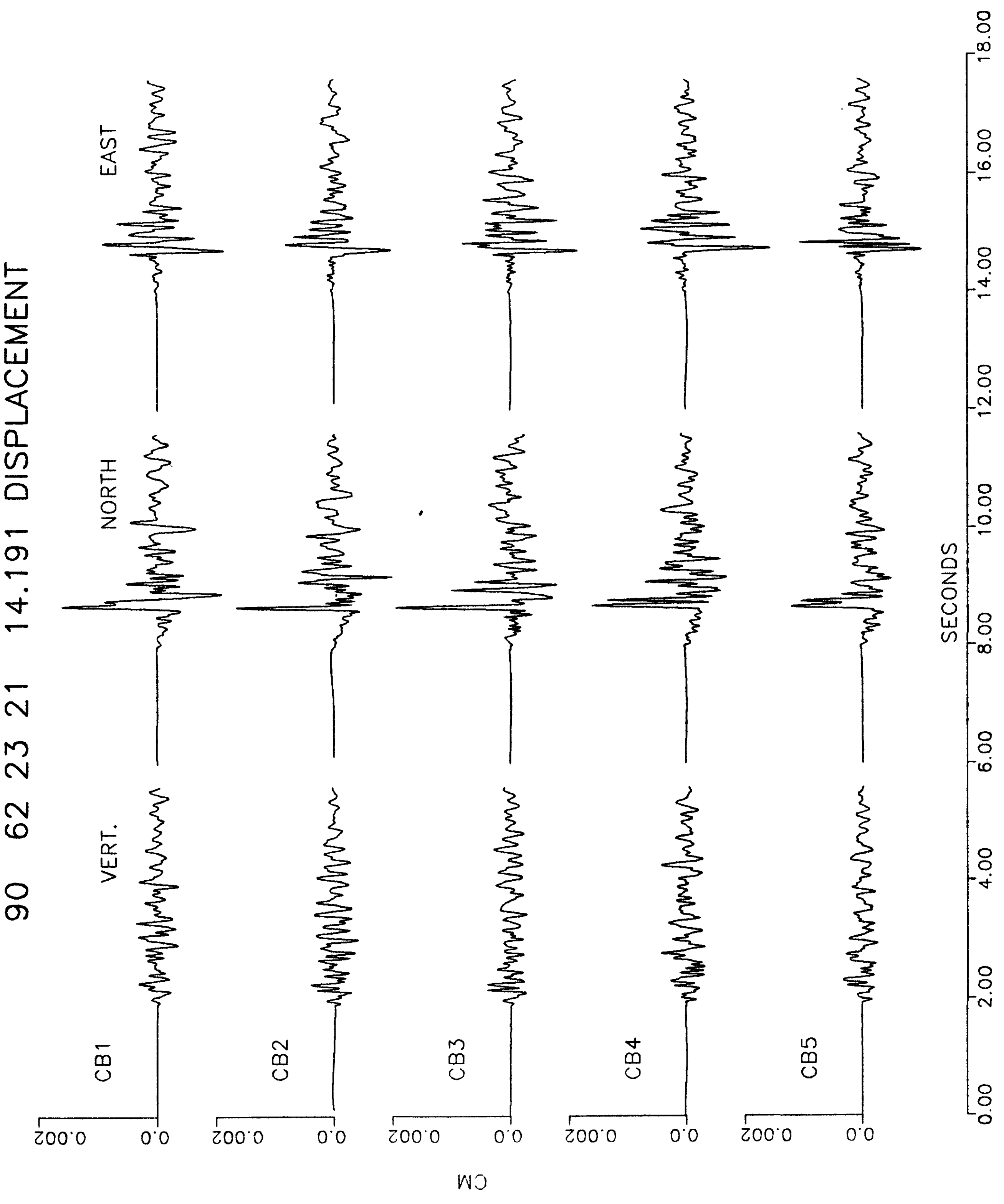
90 62 5 2 27.850 VELOCITY
VERT.
NORTH
EAST
CB1
CB2
CB3
CB4
CB5
0.02
0.0
CM/SEC
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
SECONDS

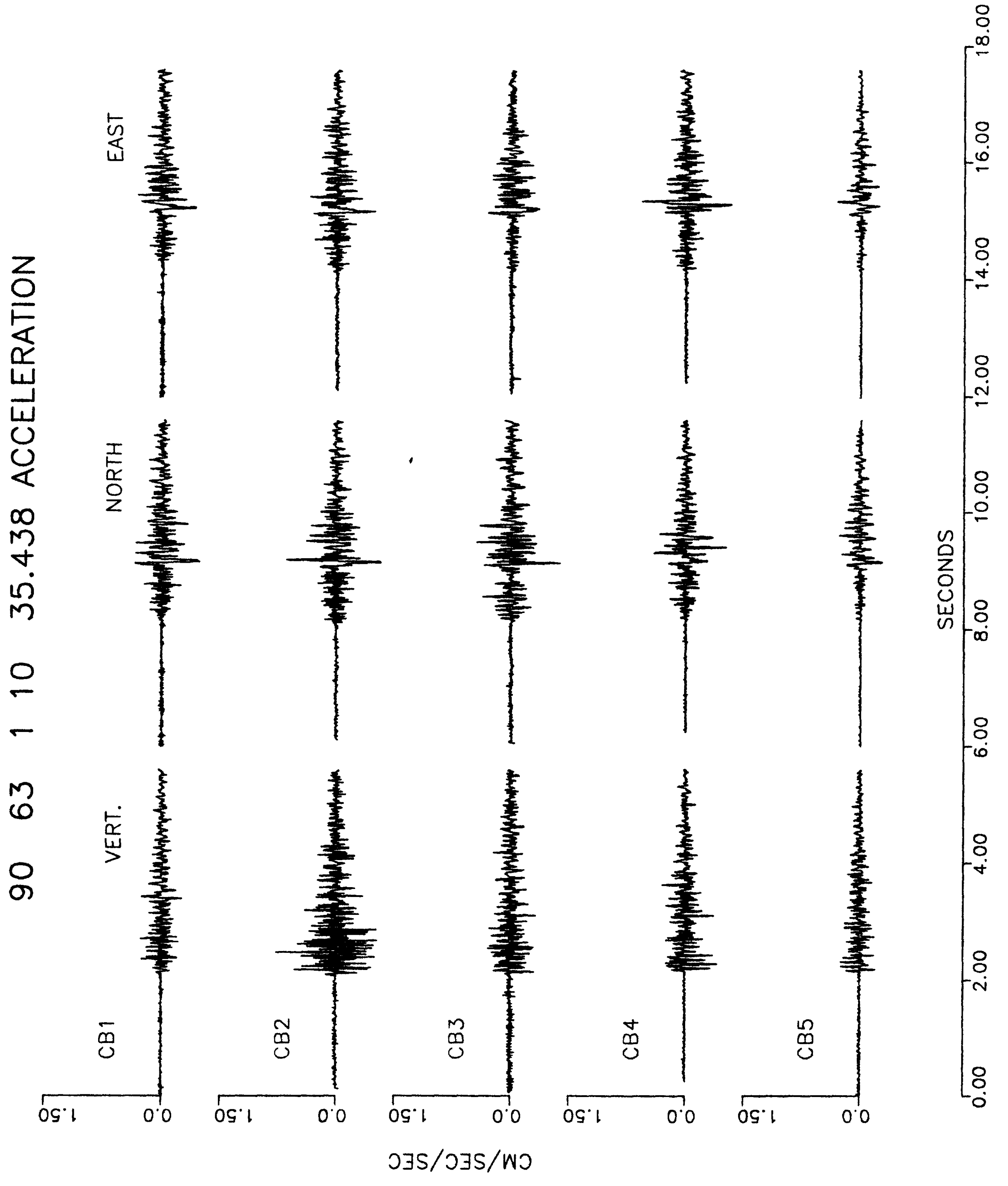

90 62 5 2 27.850 DISPLACEMENT
VERT.
NORTH
EAST
CB1
CB2
CB3
CB4
CB5
0.0002
0.0
CM
SECONDS
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00

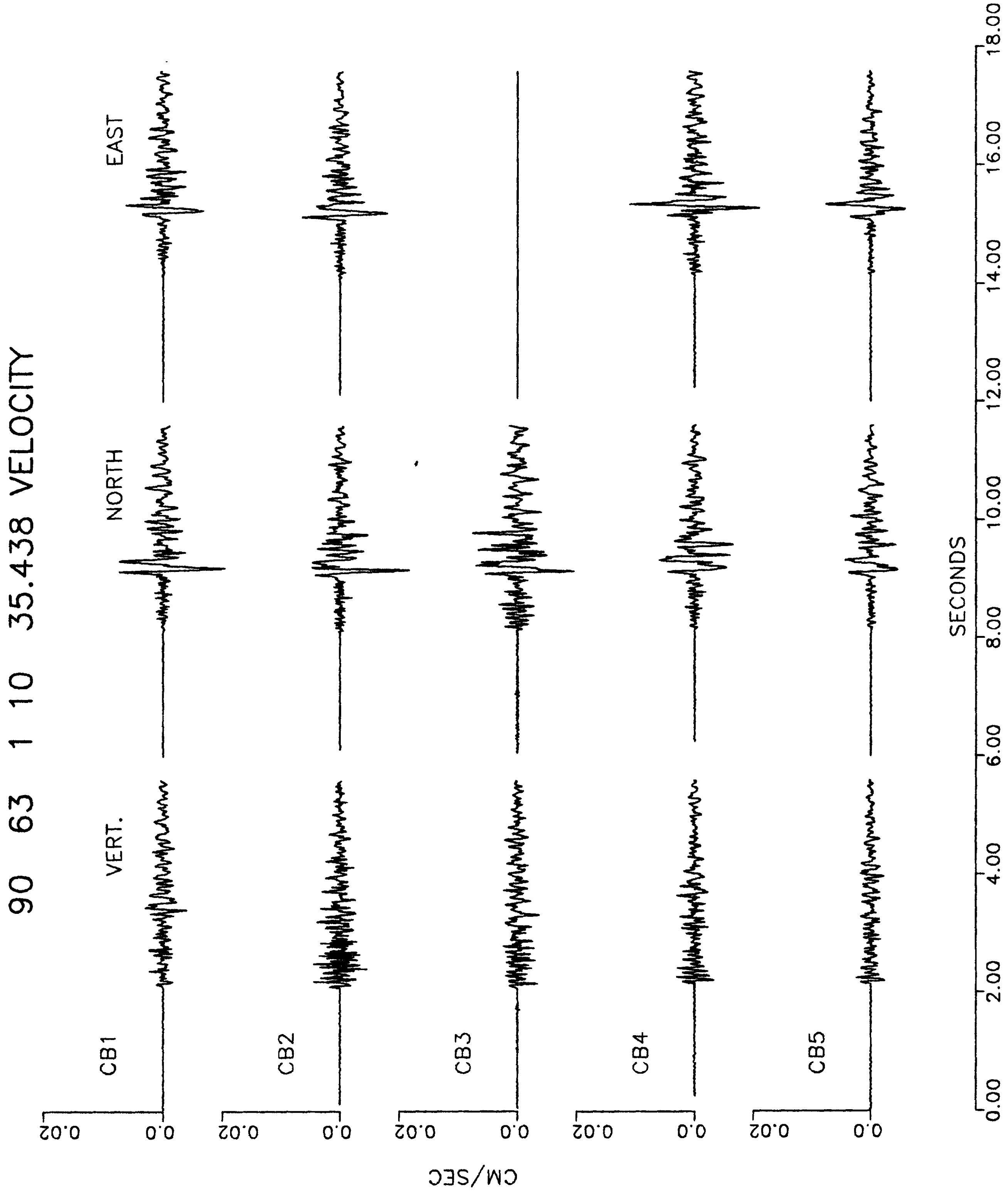

90 62 23 21 14.191 ACCELERATION
VERT.
NORTH
EAST
CB1
CB2
CB3
CB4
CB5
13.01
0.0
CM/SEC/SEC
SECONDS
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00



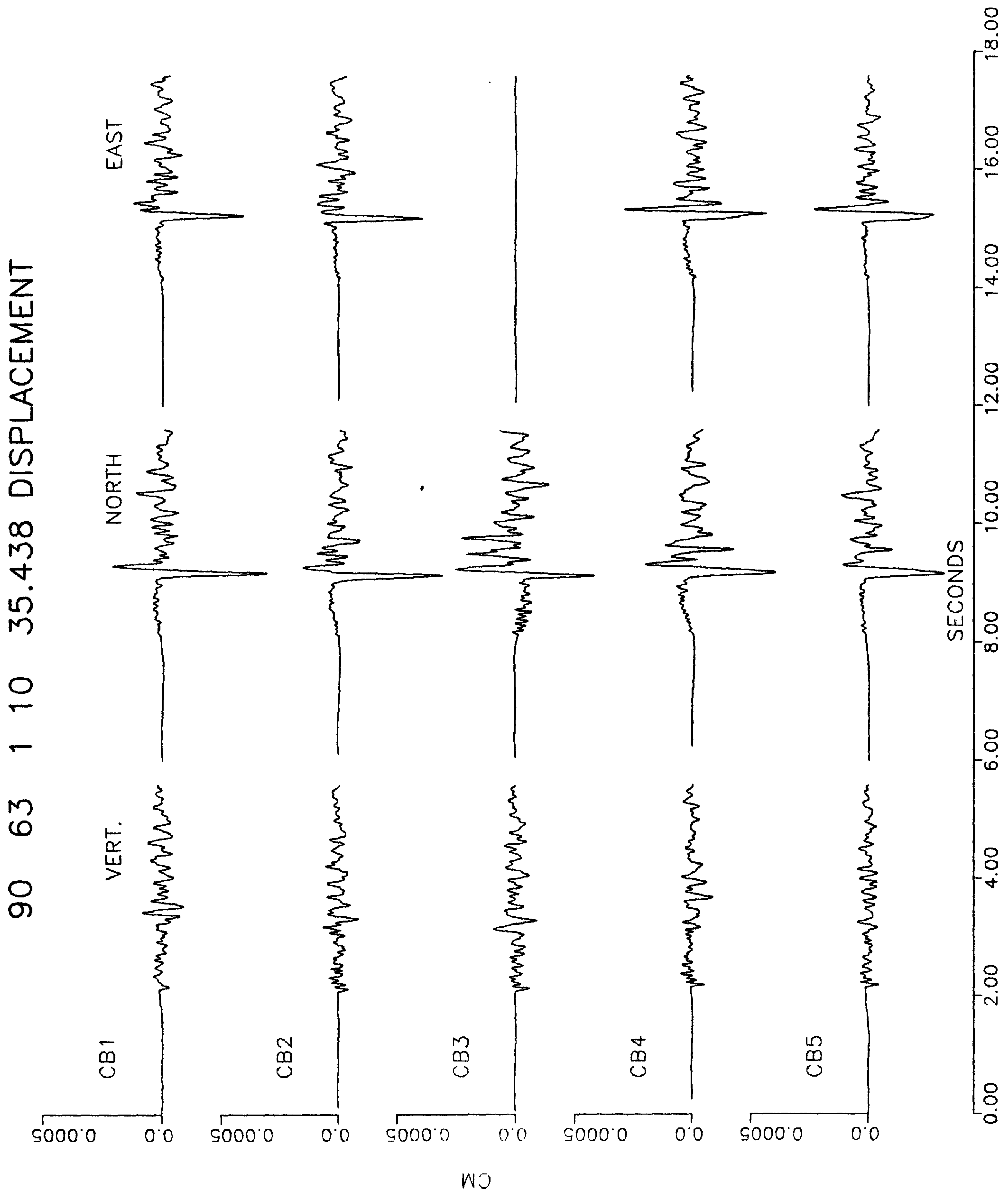
90 62 23 21 14.191 VELOCITY
VERT.
NORTH
EAST
CB1
CB2
CB3
CB4
CB5
0.13
0.0
CM/SEC
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
SECONDS

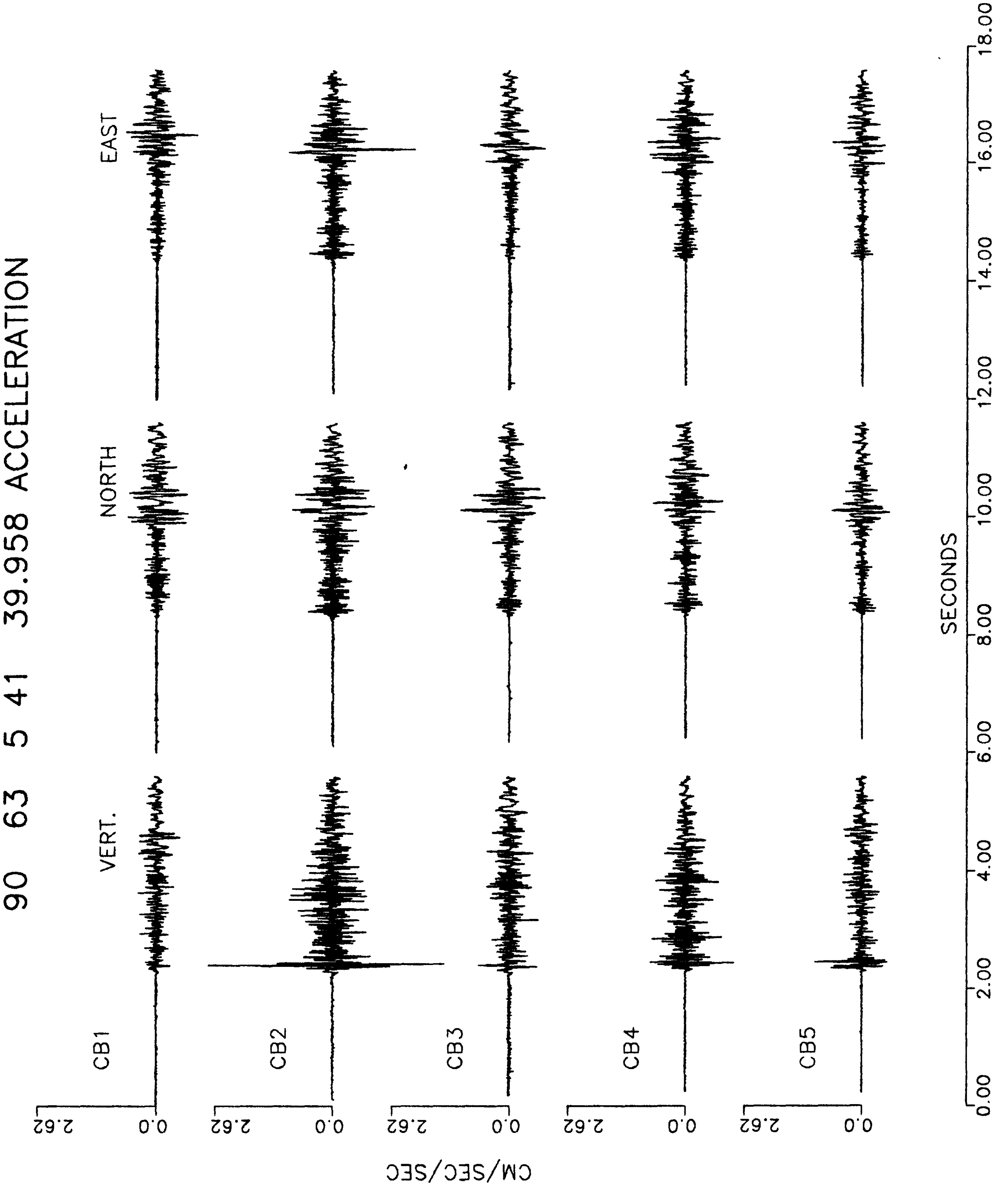

90 62 23 21 14.191 DISPLACEMENT
VERT.
NORTH
EAST
CB1
CB2
CB3
CB4
CB5
0.0
0.002
CM
SECONDS
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00

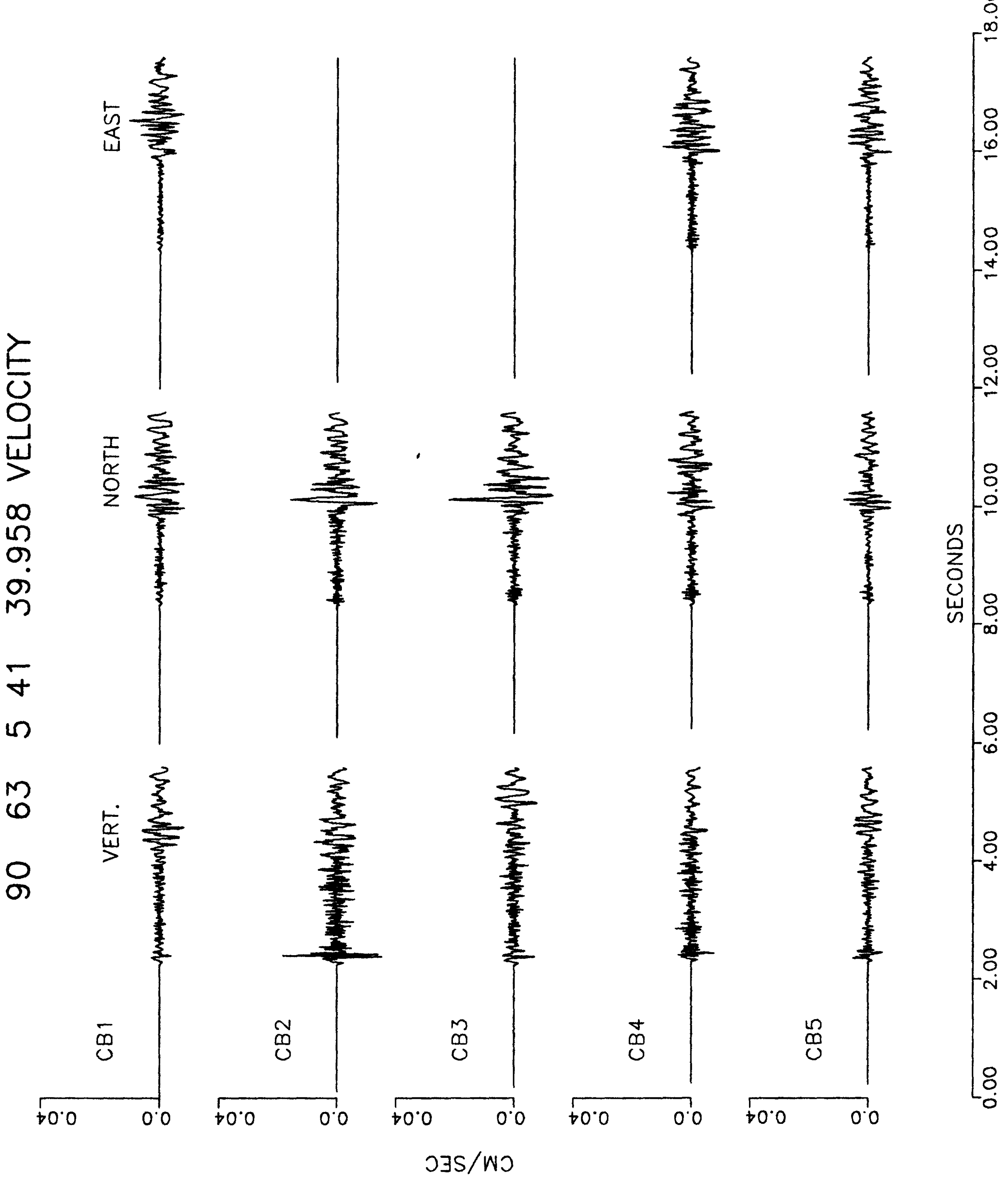

90 63 1 10 35.438 ACCELERATION
VERT.
NORTH
EAST
CB1
CB2
CB3
CB4
CB5
CM/SEC/SEC
1.50
0.0
SECONDS
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00

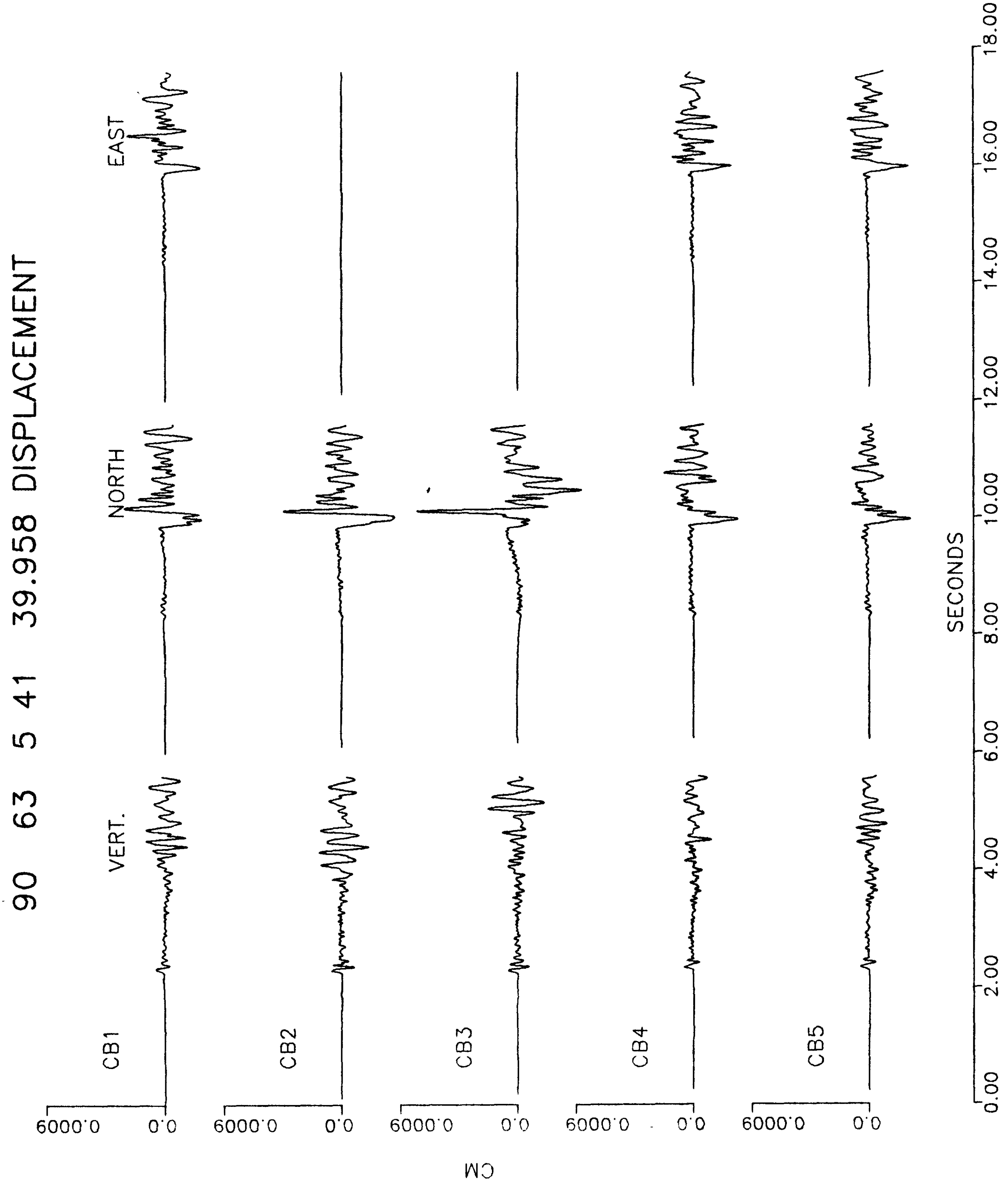


90 63 1 10 35.438 VELOCITY
VERT.
NORTH
EAST
CB1
CB2
CB3
CB4
CB5
CM/SEC
0.0
0.02
SECONDS
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00

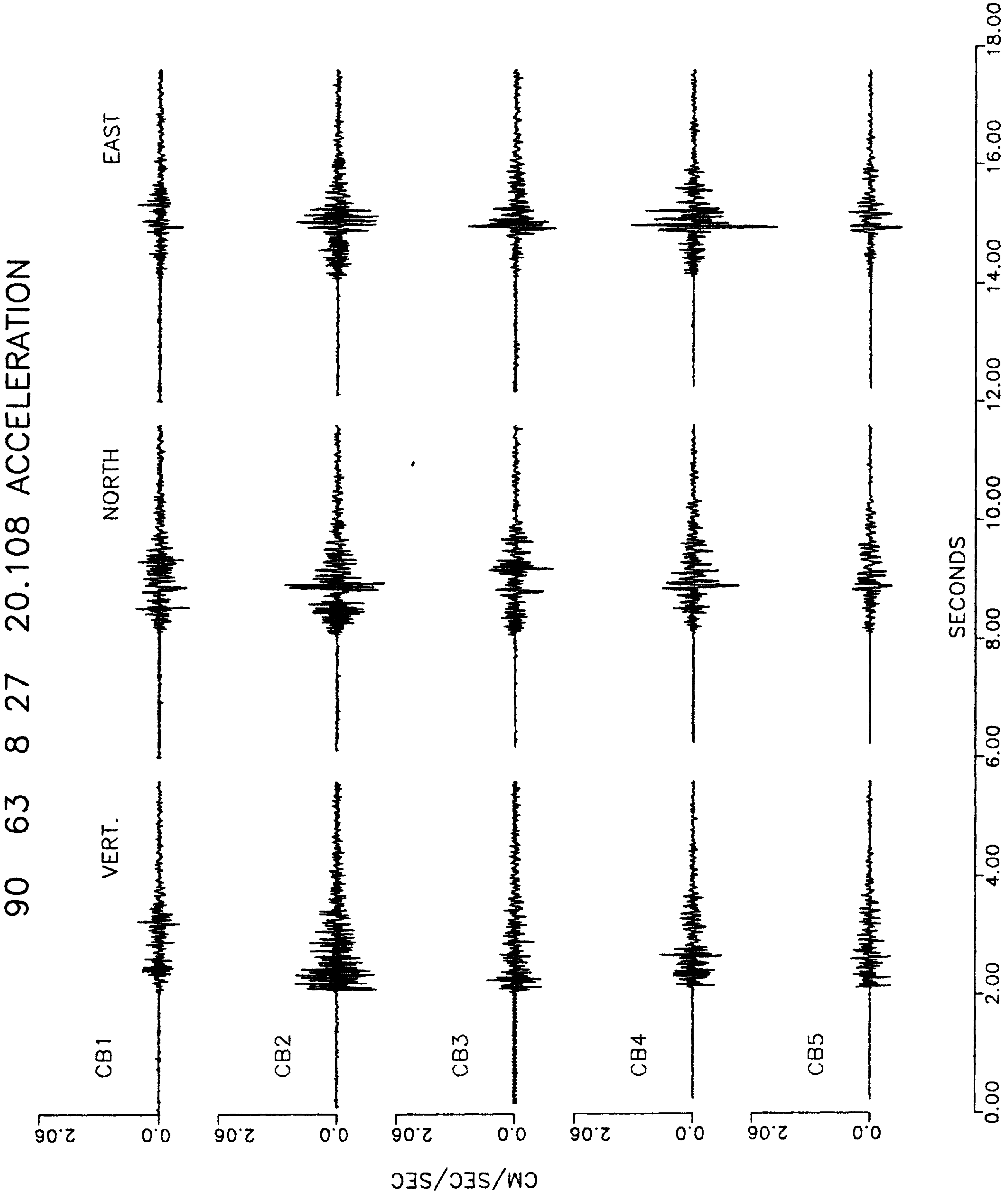

90 63 1 10 35.438 DISPLACEMENT
VERT.
NORTH
EAST
CB1
CB2
CB3
CB4
CB5
0.0
0.0005
CM
SECONDS
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00

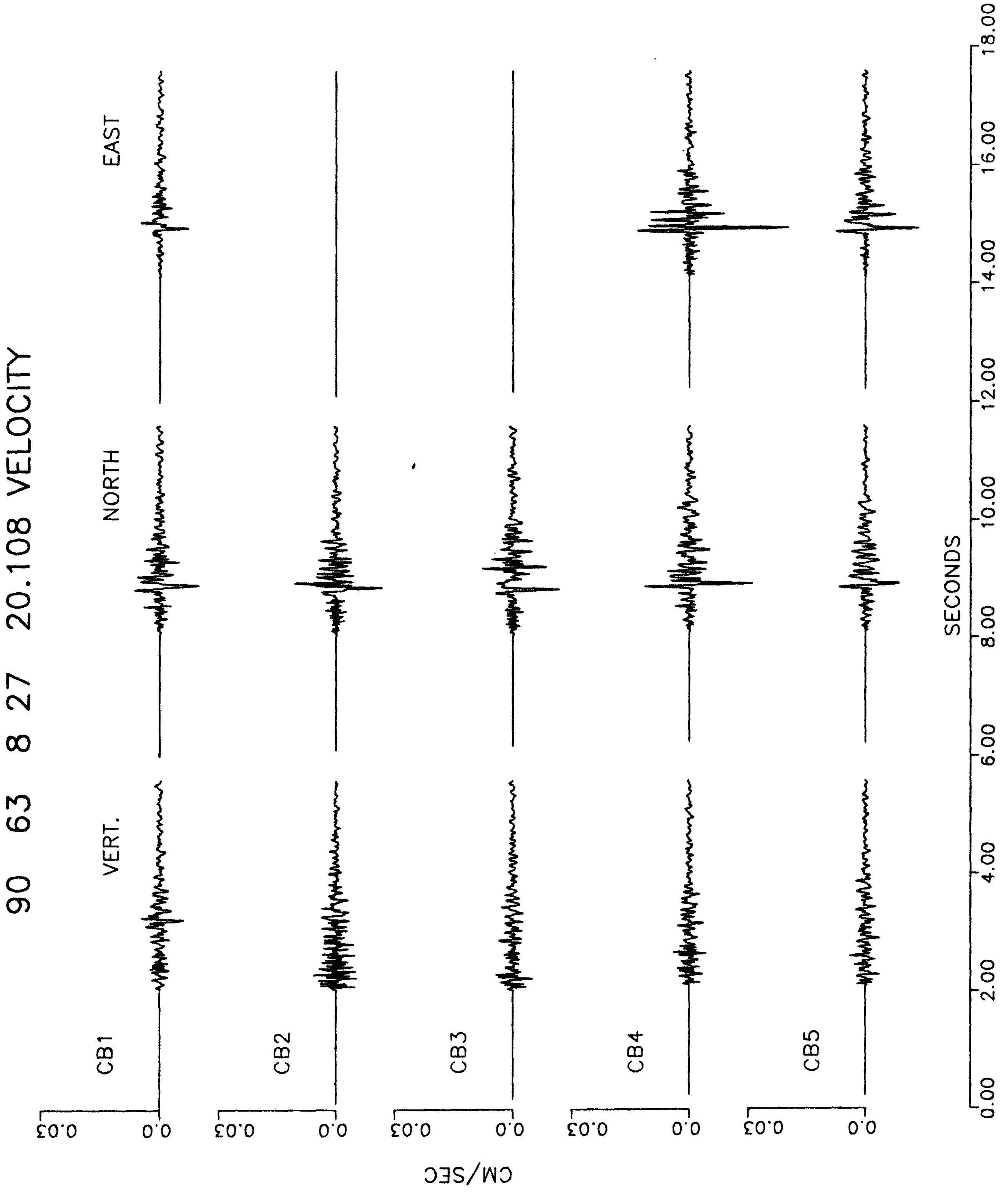

90 63 5 41 39.958 ACCELERATION
VERT.
NORTH
EAST
CB1
CB2
CB3
CB4
CB5
2.62
0.0
CM/SEC/SEC
SECONDS
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00

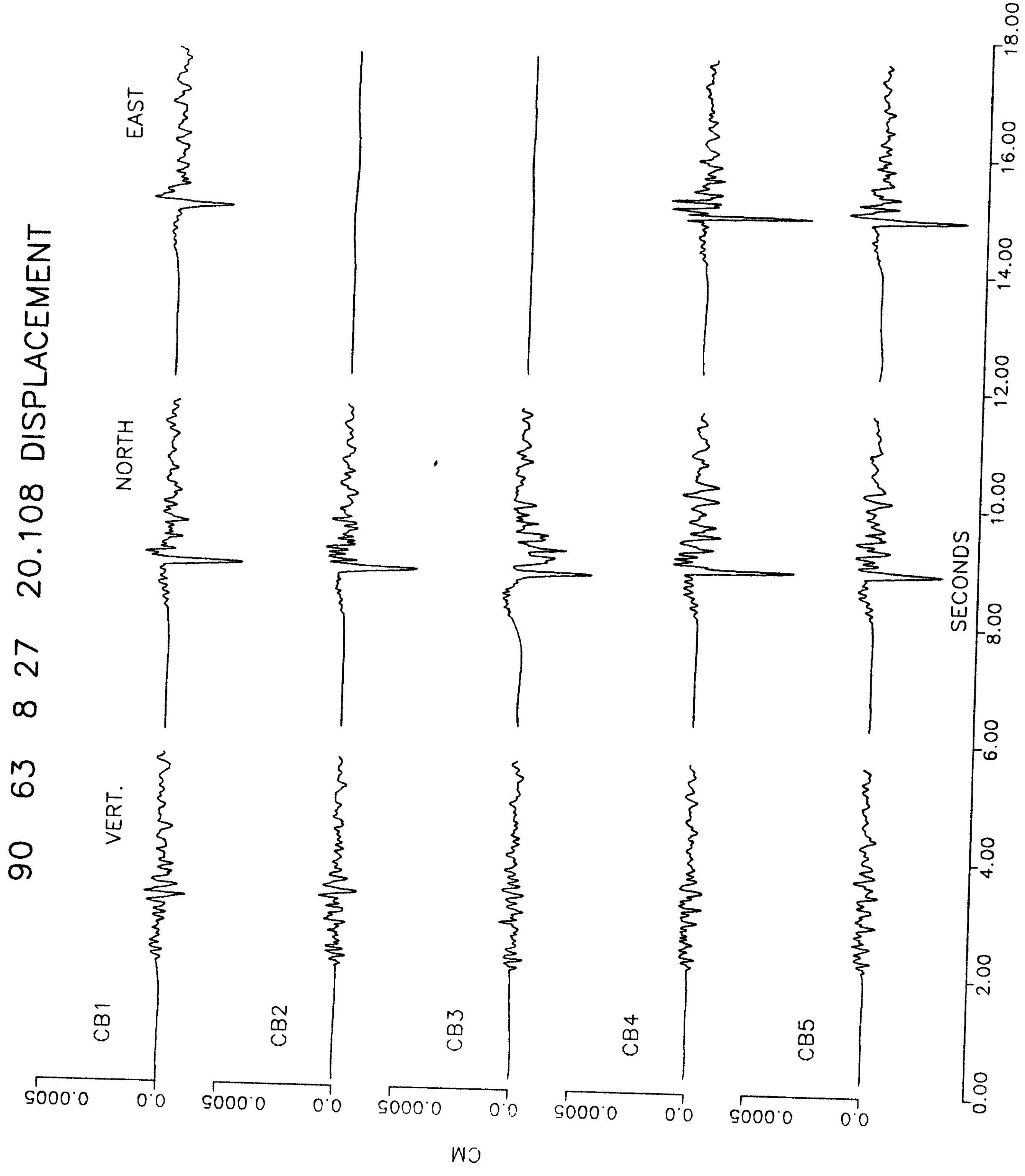

90 63 5 41 39.958 VELOCITY
VERT.
NORTH
EAST
CB1
CB2
CB3
CB4
CB5
0.04
0.0
CM/SEC
SECONDS
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00

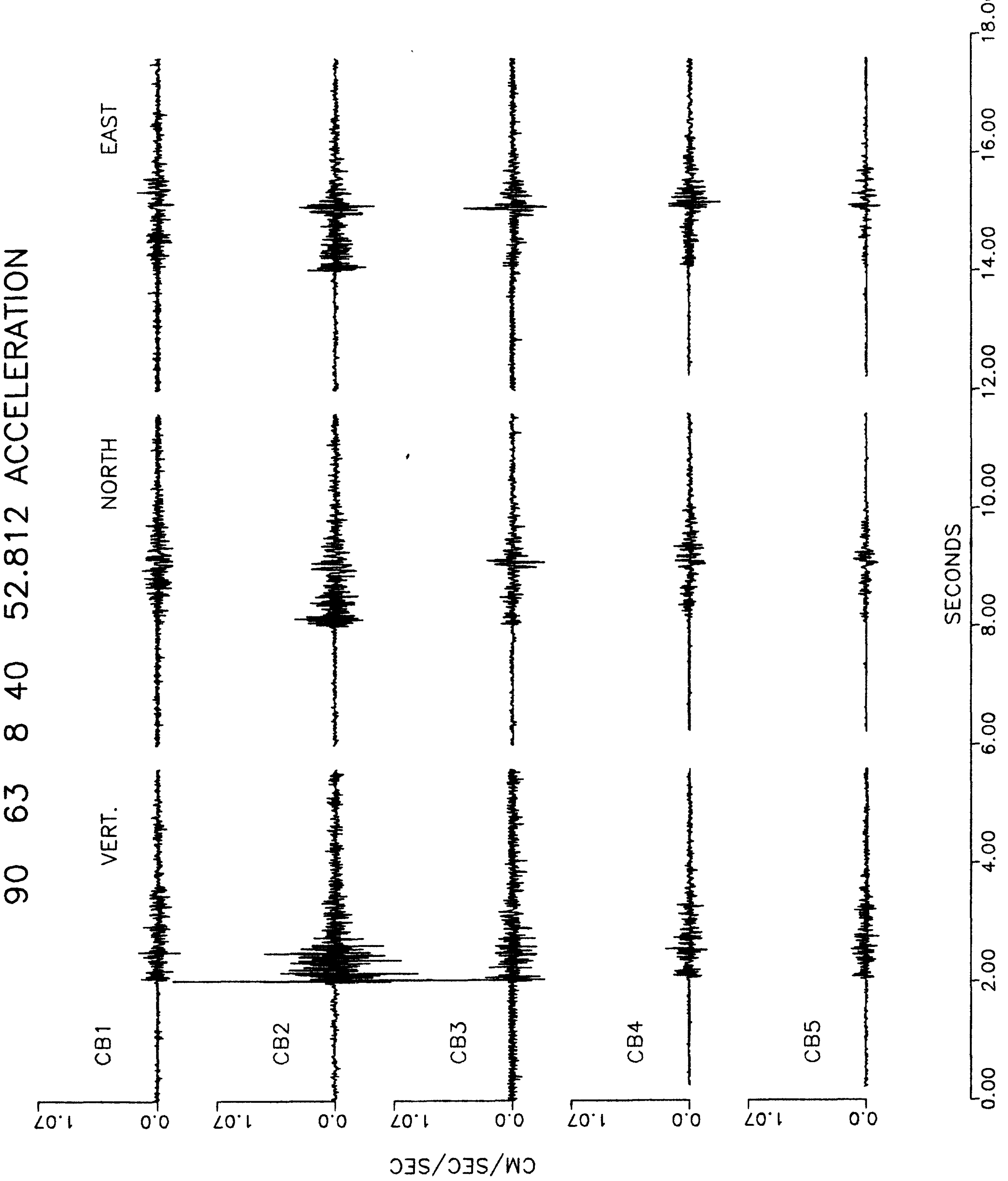


90 63 5 41 39.958 DISPLACEMENT
VERT.
NORTH
EAST
CB1
CB2
CB3
CB4
CB5
0.0
0.0009
CM
SECONDS
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00

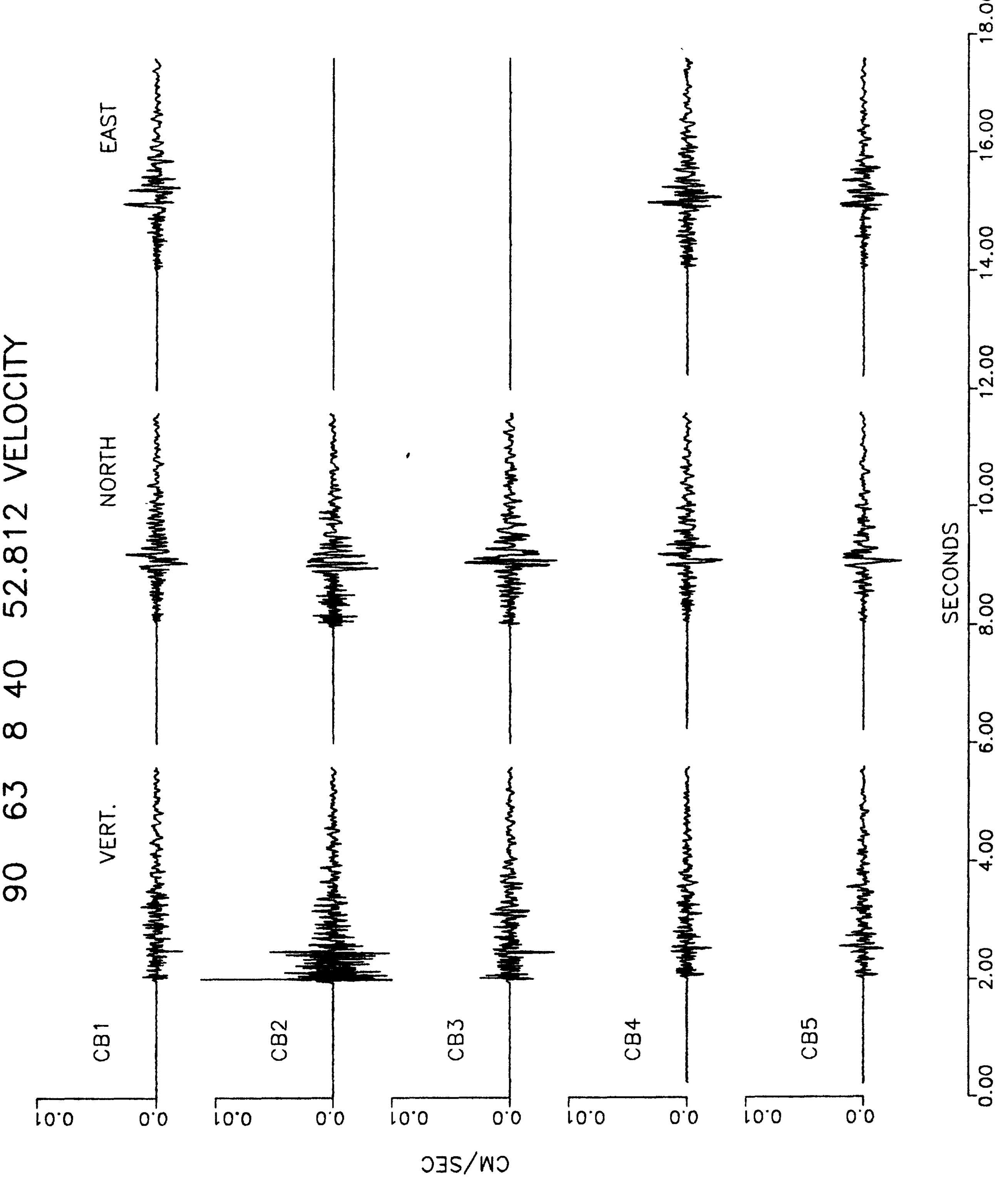

90 63 8 27 20.108 ACCELERATION
VERT.
NORTH
EAST
CB1
CB2
CB3
CB4
CB5
2.06
0.0
CM/SEC/SEC
SECONDS
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00


90 63 8 27 20.108 VELOCITY
VERT.
NORTH
EAST
CB1
CB2
CB3
CB4
CB5
0.0
0.03
CM/SEC
SECONDS
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00

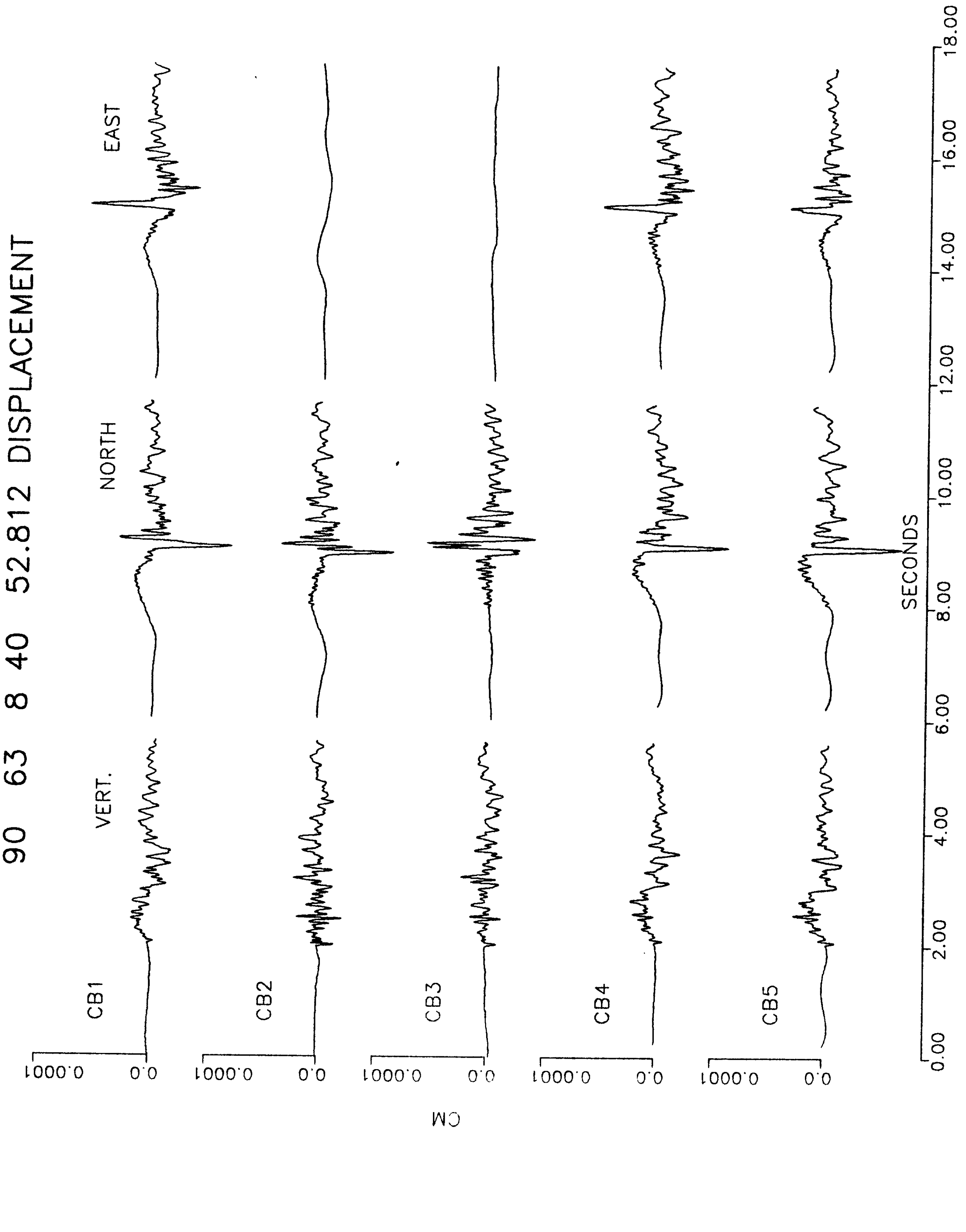

90 63 8 27 20.108 DISPLACEMENT
VERT.
NORTH
EAST
CB1
CB2
CB3
CB4
CB5
0.0
0.0005
CM
SECONDS
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00

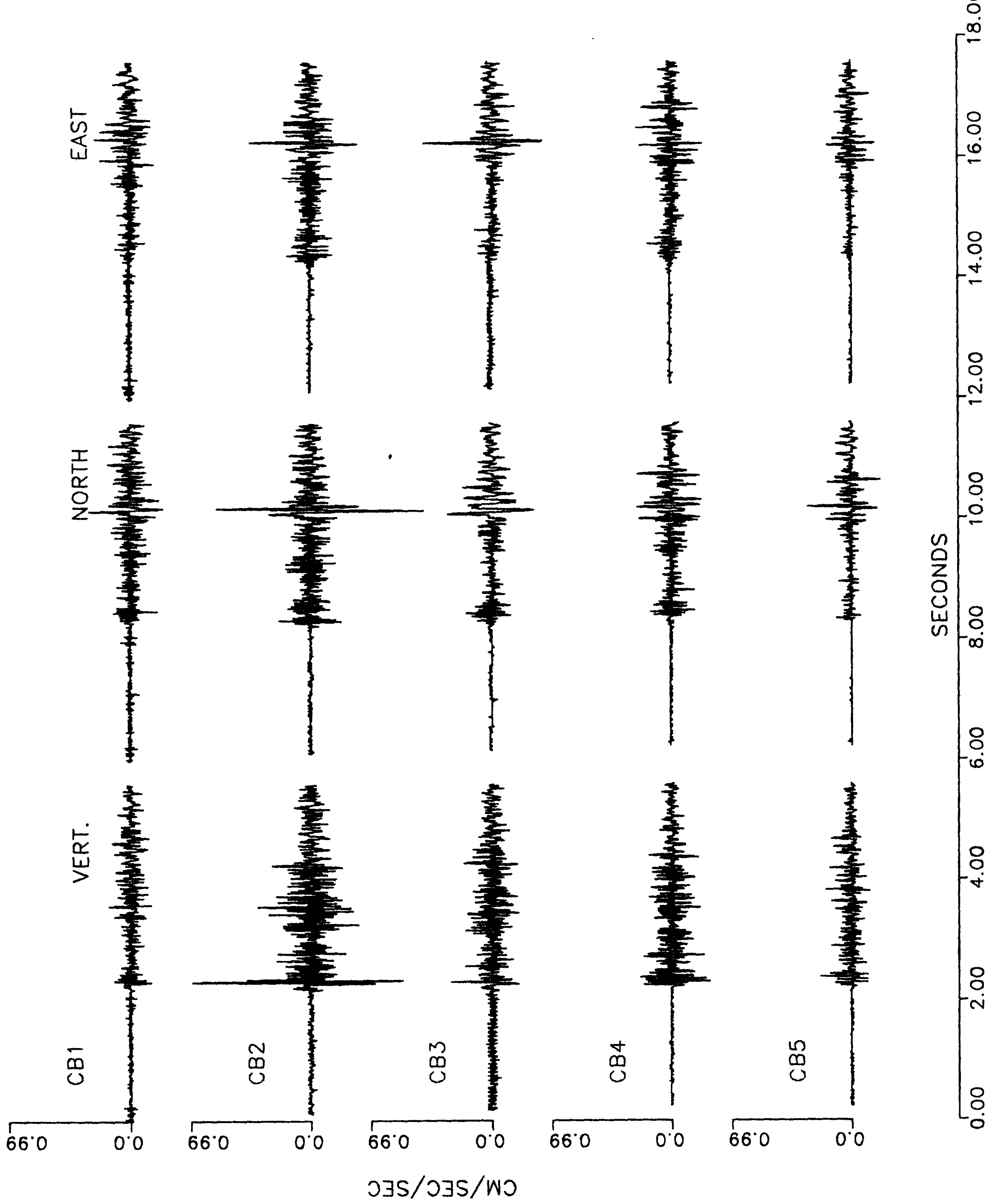


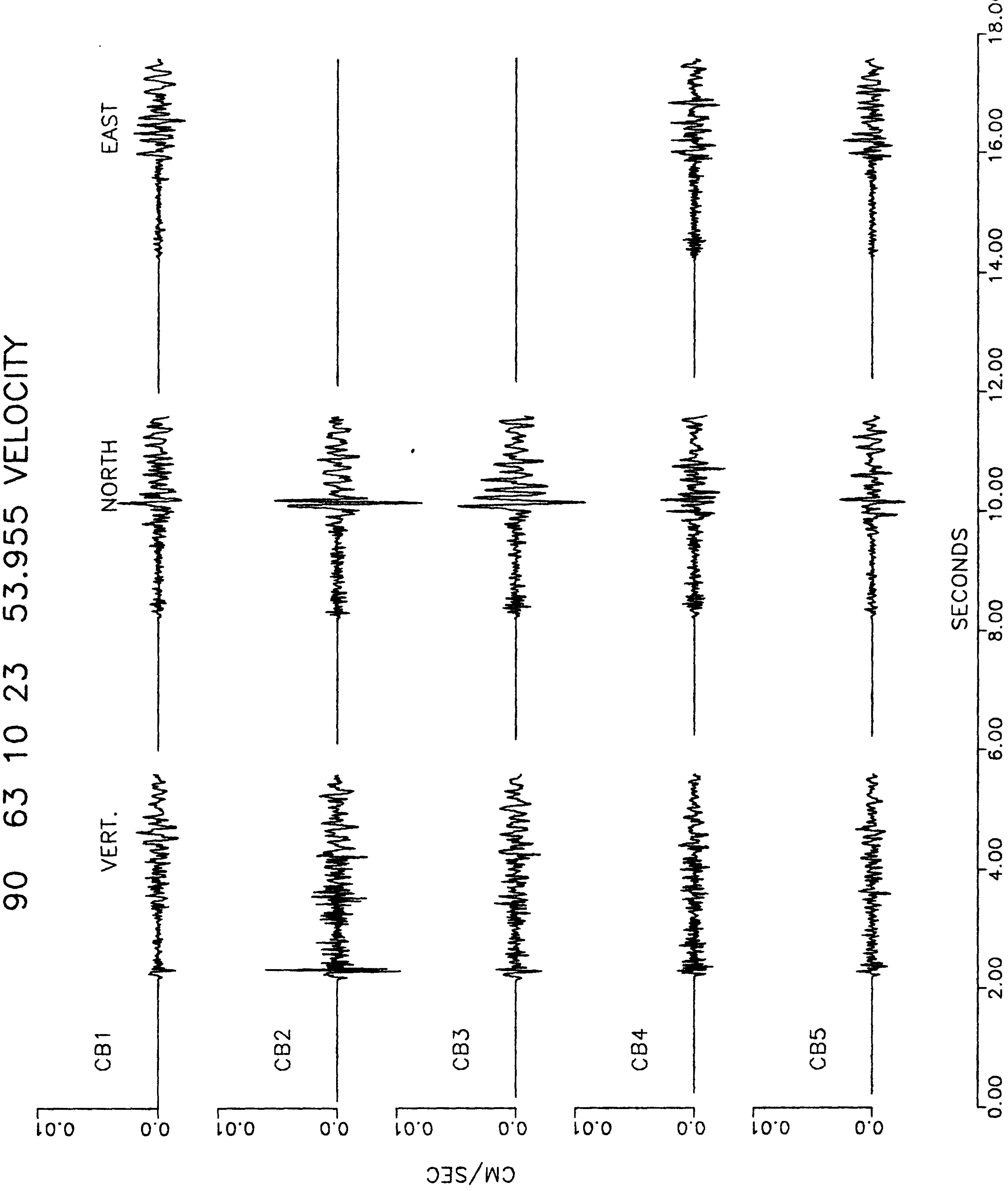
90 63 8 40 52.812 ACCELERATION
VERT.
NORTH
EAST
CB1
CB2
CB3
CB4
CB5
1.07
0.0
CM/SEC/SEC
SECONDS
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00

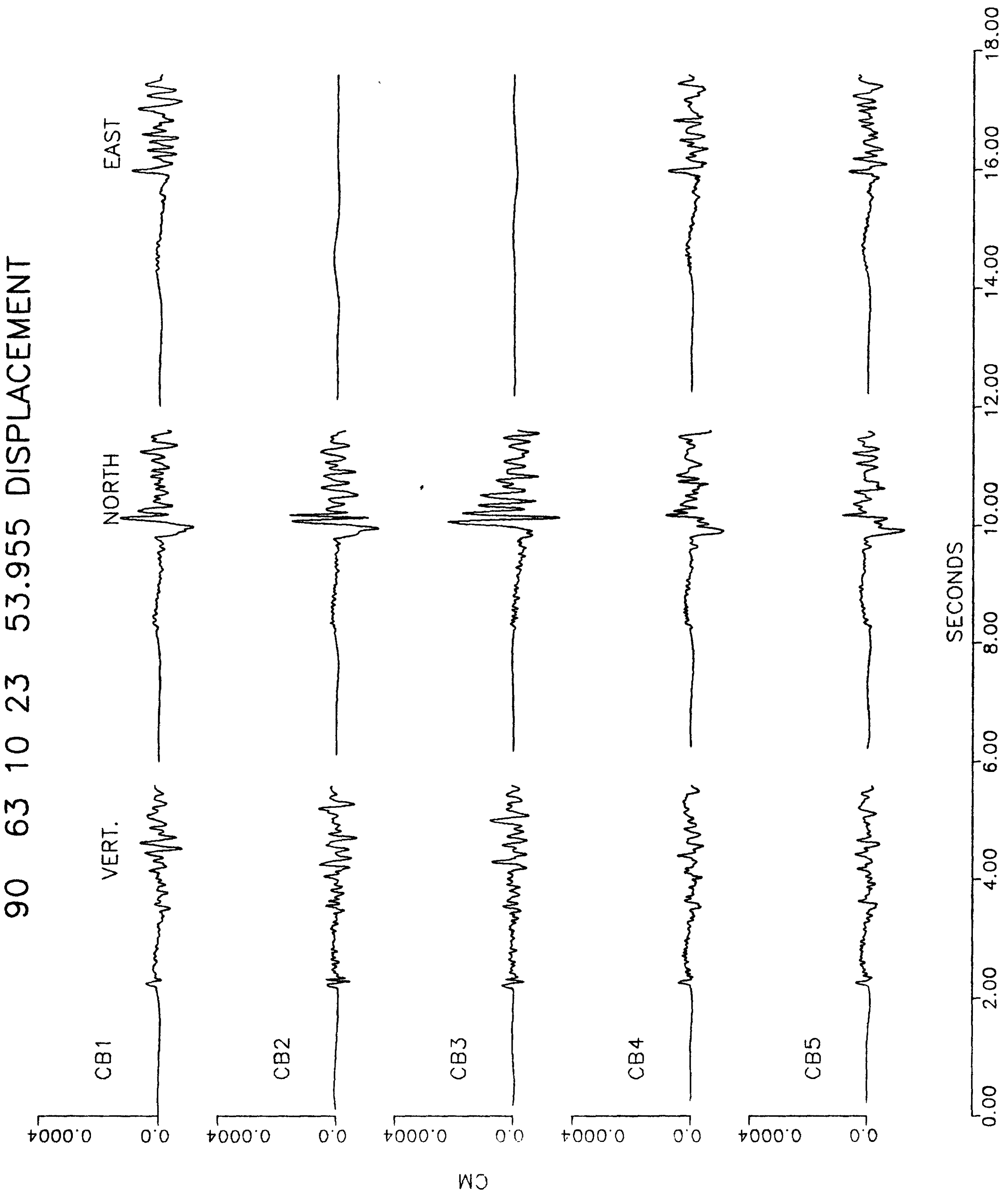


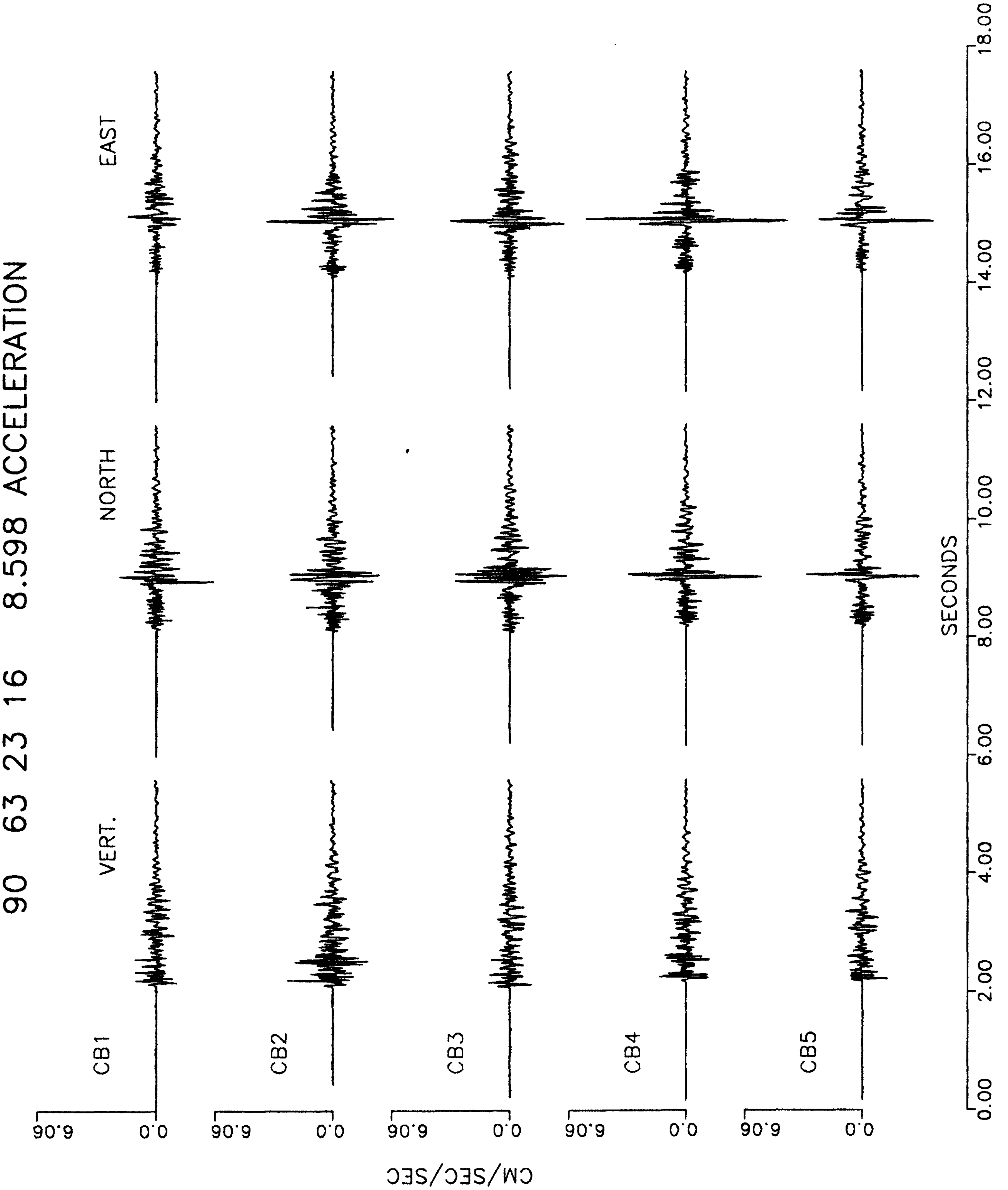
90 63 8 40 52.812 VELOCITY
VERT.
NORTH
EAST
CB1
CB2
CB3
CB4
CB5
0.0
0.01
CM/SEC
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
SECONDS

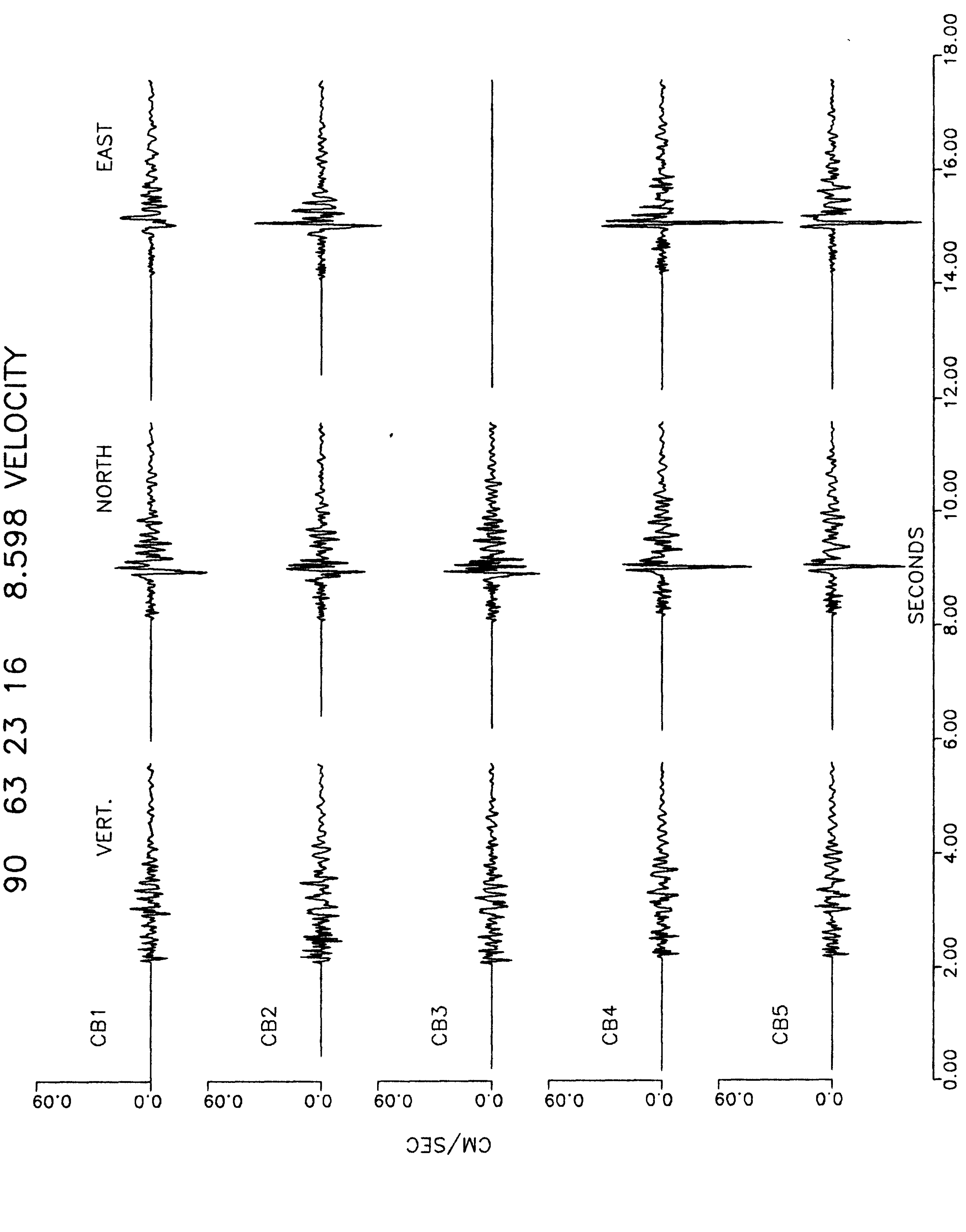

90 63 8 40 52.812 DISPLACEMENT
VERT.
NORTH
EAST
CB1
CB2
CB3
CB4
CB5
0.0001
0.0
CM
SECONDS
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00

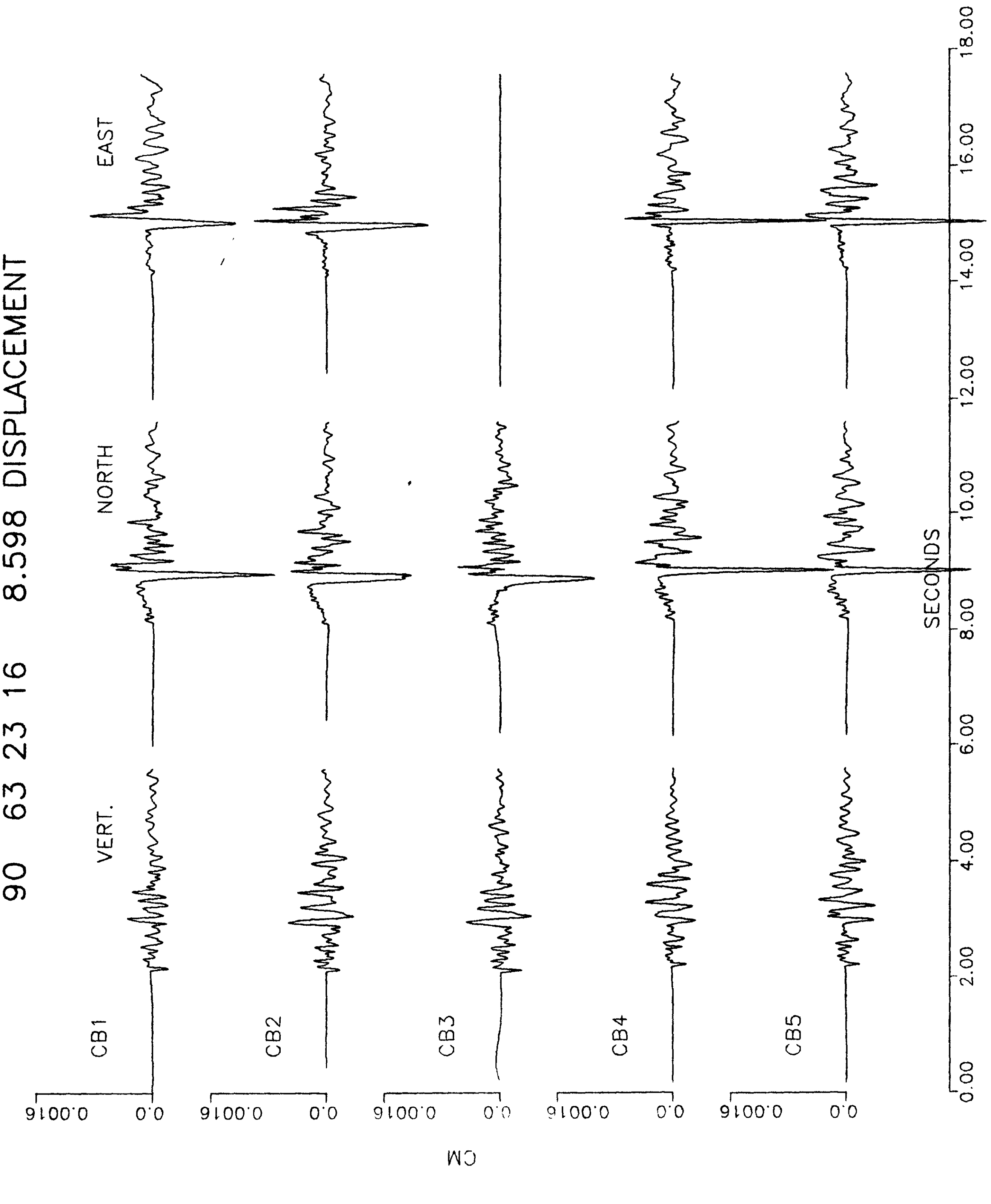

90 63 10 23 53.955 ACCELERATION
VERT.
NORTH
EAST
CB1
CB2
CB3
CB4
CB5
0.0
99.0
CM/SEC/SEC
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
SECONDS


90 63 10 23 53.955 VELOCITY
VERT.
NORTH
EAST
CB1
CB2
CB3
CB4
CB5
0.01
0.0
CM/SEC
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
SECONDS


90 63 10 23 53.955 DISPLACEMENT
VERT.
NORTH
EAST
CB1
CB2
CB3
CB4
CB5
0.0004
0.0
CM
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
SECONDS


90 63 23 16 8.598 ACCELERATION
VERT.
NORTH
EAST
CB1
CB2
CB3
CB4
CB5
CM/SEC/SEC
6.06
0.0
SECONDS
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00


90 63 23 16 8.598 VELOCITY
VERT.
NORTH
EAST
CB1
CB2
CB3
CB4
CB5
0.09
0.0
CM/SEC
SECONDS
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00



90 63 23 16 8.598 DISPLACEMENT
VERT.
NORTH
EAST
CB1
CB2
CB3
CB4
CB5
0.0016
0.0
CM
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
SECONDS