LAUR-93-3438

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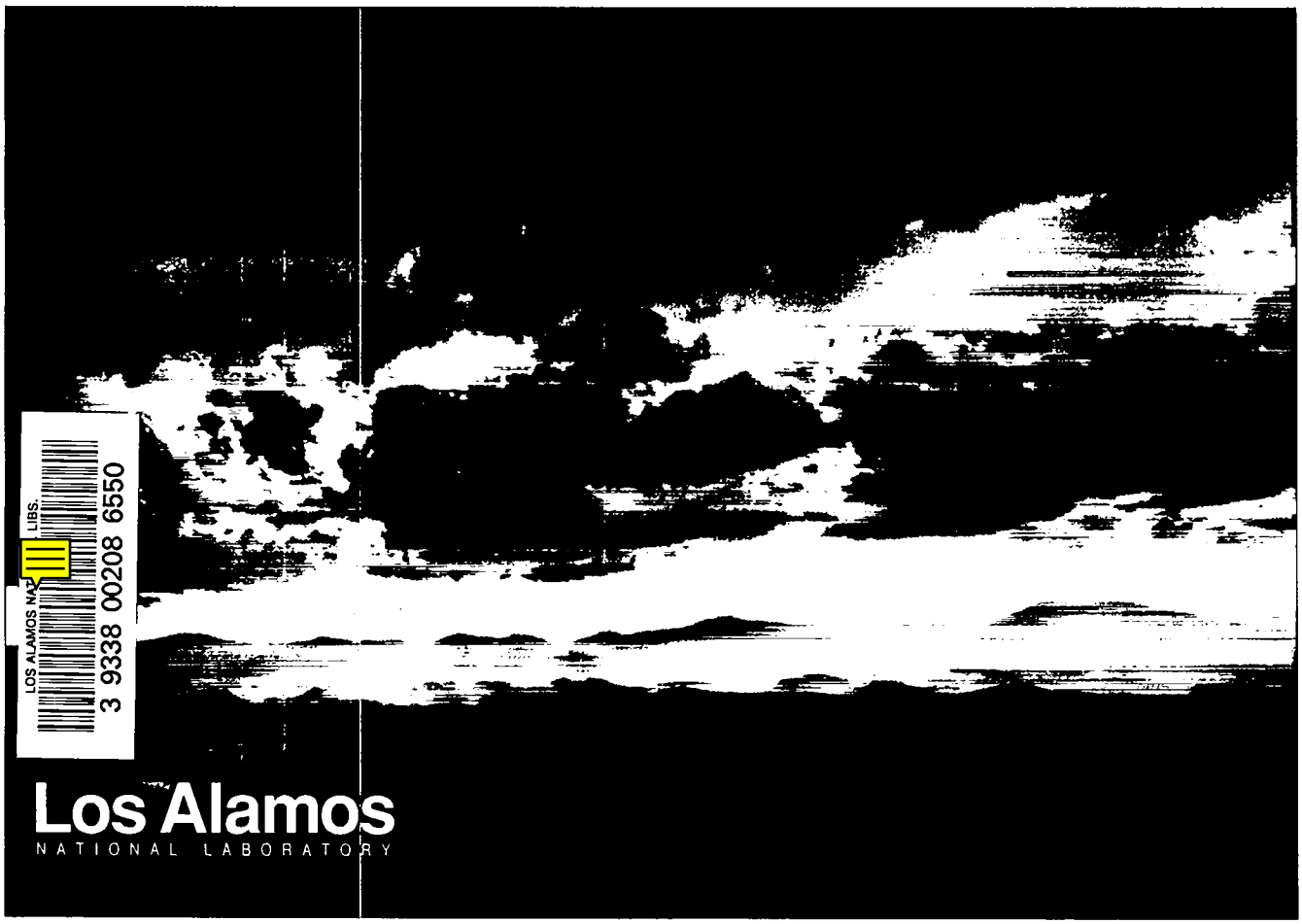
INTEGRATED VERIFICATION EXPERIMENT DATA COLLECTED AS PART OF THE LOS ALAMOS NATIONAL LABORATORY'S SOURCE REGION PROGRAM

APPENDIX B:

SURFACE GROUND MOTION

T.A. Weaver, D.F. Baker, C.L. Edwards, and S.H. Freeman

LOS ALAMOS SOURCE REGION PROGRAM



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APPENDIX B

SURFACE GROUND MOTION

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October 1993

Abstract

Surface ground motion was recorded for many of the Integrated Verification Experiments using standard 10-, 25- and 100-g accelerometers, force-balanced accelerometers and, for some events, using golf balls and 0.39-cm steel balls as surface inertial gauges (SIGs). This report contains the semi-processed acceleration, velocity, and displacement data for the accelerometers fielded and the individual observations for the SIG experiments. Most acceleration, velocity, and displacement records have had calibrations applied and have been deramped, offset corrected, and deglitched but are otherwise unfiltered or processed from their original records. Digital data for all of these records are stored at Los Alamos National Laboratory.

Table of Contents

1. Introduction B-1
2. Measurement Types B-1
   2.1 J-8 Surface Accelerometer Measurements B-2
   2.2 Extended Surface Accelerometer Measurements B-2
   2.3 GRMPY B-3
   2.4 Surface Initial Gauges B-3
3. Surface Motion Data for the IVEs B-4
4. Event Data B-4
   4.1 Misty Echo (U12n.23) B-5
   4.2 Texarkana (U7ca) B-23
   4.3 Tulia (U4s) B-39
   4.4 Contact (U20aw) B-51
   4.5 Amarillo (U19ay) B-57
   4.6 Hornitos (U20bc) B-73
   4.7 Metropolis (U2gg) B-83
   4.8 Mineral Quarry (U12n.22) B-127
   4.9 Bexar (U19ba) B-161
   4.10 Junction (U19bg) B-209
5. Additional Information B-227

List of Figures

1. Misty Echo station map B-5
2. Misty Echo station data traces for the accelerometers B-7
3. Ground-motion-measurement array for Texarkana B-23
4. Texarkana station data traces for the accelerometers B-25
5. Ground-motion-measurement array for Tulia B-39
6. Tulia station data traces for the accelerometers B-41
7. Contact/Amarillo experiment map B-52
8. Ground-motion stations for Amarillo B-59
9. Amarillo station data traces for the accelerometers B-65
10. Hornitos experimental plan B-75
11. Metropolis deployment locations B-85
12. Results of the SIG experiment on Metropolis. B-88
13. Spall limit on Metropolis as determined from the extended accelerometer array data. B-89
14. Metropolis station data traces for the accelerometers B-95
15. Mineral Quarry station map. B-128
16. Mineral Quarry station data traces for the accelerometers B-131
17. Bexar station map B-162
18. Bexar station data traces for the accelerometers B-165

19. Junction SIG experiment plan....B-210
20. Junction station map....B-211
21. Junction data traces for the accelerometers....B-215

List of Tables

1. Misty Echo Ground-Motion Station Data....B-6
2. Texarkana Ground-Motion Station Data....B-24
3. Tulia Ground-Motion Station Data....B-40
4. SIG Arrays for Contact....B-51
5. Contact SIG Results....B-53
6. SIG Arrays for Amarillo....B-57
7. Amarillo Ground-Motion Station Data....B-58
8. Amarillo SIG Results....B-60
9. Hornitos SIG Data....B-76
10. Metropolis Ground Motion Station Data....B-86
11. Metropolis SIG Results....B-90
12. Mineral Quarry SIG Data....B-129
13. Bexar Station Data....B-163
14. Junction SIG Arrays....B-209
15. Junction Ground-Motion Station Data....B-212
16. Junction SIG Results....B-213

1. Introduction

Ground-motion analysis has been a key part of the Los Alamos National Laboratory (LANL) Source Region Program (SRP) for several reasons: near-source ground motion represents the up-going energy from an underground explosion, and that information is required to assess the total energy budget for an explosion; these data can be used to benchmark the numerical modeling of the nonlinear zone; and last, but not least, later time phenomena, such as spall closure, are believed to play significant roles in seismic and other signals used for detection, discrimination, and characterization of underground explosions. As a result, characterization of the close-in ground motions has been a major goal of the SRP.

One of the topics being addressed by the SRP is the three-dimensional characterization of the spall volume as a function of time (size, shape, volume, mass, ground motions, surface expression, and degree of damage). Surface observations of acceleration, velocity, and displacement provide constraints for spall and, when combined with the limited amount of subsurface ground-motion data (not presented in this report), allow a three-dimensional model to be generated.

Presented herein are the data from a variety of close-in ground-motion experiments conducted by LANL and its collaborators, Southern Methodist University (SMU) and the Defense Nuclear Agency, Albuquerque (DNA/A), on the 12 Integrated Verification Experiments (IVEs) of the SRP. Only 10 of the IVEs had ground-motion experiments performed; Ingot (U2gg) and Bullion (20bd) did not.

These data are the semi-processed acceleration, velocity, and displacement records for the accelerometers fielded and the individual observations for the surface inertial gauge (SIG) experiments. Most acceleration, velocity, and displacement records have had calibrations applied and have been deramped, offset corrected, and deglitched but are otherwise unfiltered or processed from their original records.

2. Measurement Types

Four types of ground-motion measurements were performed for the IVEs: (1) the standard J-8 surface accelerometer installation for the Nuclear Test Containment Program, deployed only on LANL-sponsored events; (2) extended surface accelerometer (ESA) measurements to define and characterize the spall zone; (3) GRMPY stations installed at and around surface ground zero (SGZ) for some events; and (4) arrays of SIGs to fill in those areas where we could not afford to place instrumentation. Not all types were used on each IVE; type 1 was deployed only on LANL-sponsored events; types 2 through 4 were added as needed to observe the ground motions at and around SGZ, through the spall zone, and beyond.

2.1 J-8 Surface Accelerometer Measurements. LANL Group J-8 has instrumented the SGZ area on LANL-sponsored events with accelerometers (among other types of sensors) for the Test Director (and later, the Containment Program) since the first underground nuclear tests. In the latter half of this effort, the measurement array for these instruments has been standardized to include: one to three stations at SGZ, two stations at the trailer park (normally located near the perimeter fence); three or four stations at the perimeter fence, normally at azimuths 90° to 120° apart, and three or four stations at about one hole depth, 90° to 120° apart. Each station typically has three components of motion: vertical, radial, and tangential, though in some cases, only verticals have been employed. The accelerometers used for these stations are Endevco 10-, 25-, or 100-g instruments (Model 2262), depending on the anticipated motions. The plus directions on the data plots presented herein are: vertical, up; radial, toward SGZ; and tangential, clockwise around SGZ.

The data are recorded by the remote instrumentation digital system (RIDS). The input analog signals are low-pass-filtered to 100 Hz and digitized at 640 Hz. J-8 has preprocessed the data, which may include corrections for timing, amplitude calibration, baseline offsets, integration ramps, noise, etc. EG&G and EES-3 may also have further corrected these signals for residual integration ramps and baseline offsets.

Note: Offset or integral ramp corrections may not be obvious in the records presented because for clarity only the first 2 s of record are displayed in this report.

2.2 Extended Surface Accelerometer (ESA) Measurements. For some events, we have acquired ground-motion data that straddled the edge of predicted spall (Misty Echo, Metropolis, Mineral Quarry, and Bexar), and for one event, Bexar, data out to at least three times the predicted spall radius were collected. To acquire these measurements, we installed portable stations consisting of accelerometers (and in some cases, seismometers), portable power (batteries), and portable digital recorders.

The accelerometers deployed were of two main types: Model SA-111 force-balanced accelerometers, built by Terra Technology; and 10- and 25-g Model 2262A piezoelectric accelerometers by Endevco. The Endevcos were borrowed from J-8 for these experiments.

Three types of portable digital recorders were used. For the two tunnel experiments, SMU furnished 16-bit, 6-channel REFTEK data acquisition system (DAS), made by Refraction Technology, and DNA/A furnished 12-bit, 3-channel PDAS recorders by Terra Technology. For Metropolis, only SMU REFTEKs were used; for Bexar, SMU and LANL REFTEKs were used together with several of both 3- and 6-channel portable digital recorders (PDR-2s), made by Kinemetrics, furnished by LANL. Data were

recorded at several speeds, dependent upon recorders used and the nature of the experiment, ranging from 100 samples/s to 1000 samples/s.

The clocks on all of the portable digital recorders used for the four events with ESA arrays (Misty Echo, Metropolis, Mineral Quarry, and Bexar) were not the modern GPS (Global Positioning Satellite) clocks. As a result, timing for the extended accelerometer measurements on those events is suspect and has been corrected by average velocity travel times to each station. Do not attempt to draw significance from any time-of-arrival (TOA) data for these measurements.

EG&G and EES-3 have corrected these signals for timing, amplitude calibration, integration ramps, and baseline offsets.

Note: Offset or integral ramp corrections may not be obvious in the records presented because for clarity only the first 2 s of record are displayed in this report.

2.3 GRMPY. GRMPY (GRound Motion Predicts Yield) was an experimental system being developed and tested by LANL for on-site verification of the Threshold Test Ban Treaty (TTBT).[1] GRMPY employed a small array of accelerometers that were fielded in the vicinity of SGZ for an underground nuclear test and a recording van. Due to the nature of the system the locations for those stations are approximate because the stations did not require accurate surveys. Because the system was experimental, the configuration and location of the accelerometer stations, the recording system, and even the sensors could change from event to event. EG&G and EES-3 may have corrected these signals for polarity, integration ramps, and baseline offsets.

Note: Offset or integral ramp corrections may not be obvious in the records presented because for clarity only 2 s of record are displayed in this report.

2.4 Surface Inertial Gauges (SIGs). One of the major topics to be addressed by the SRP is the three-dimensional characterization of the spall volume as a function of time: size, shape, volume, mass, ground motions, surface expression, and degree of damage. Observations made on earlier events have indicated that rocks, ranging in size from small pebbles to large boulders, can be ballistically launched during the spall period. Hundreds of ground-motion gauges would be needed to map ground motion in the spall zone, assuming the complexity indicated by the postshot crack maps of many events, but an experiment of that magnitude involving electronic gauges is prohibitively expensive. Using golf balls as a type of inertial gauge seemed to be a way of getting, at least in a relative sense, fairly inexpensive information about the spall zone: size, shape, and character (uniformity, intensity, impulsiveness) of the ground motions.

[1]Deupree, R. G. et. al., MISTY ECHO Proof Test of the GRMPY System, LA-11660-MS, 43 p., January 1990

3. Surface Motion Data for the IVEs

The accelerometer data presented herein are the vertical components of surface acceleration and the derived velocity and displacement. At most ground-motion stations discussed in this report, three-component data (mainly vertical, radial, and tangential) were collected. The radial and tangential data are in the database and available should anyone require them. The data are reported as acceleration, in units of g; velocity, in m/s; and displacement, in m, for each gauge, one gauge to a page. Only those gauges with valid records are included in this report. Later experiments indicated that any ground-motion data of the type and density reported herein are spatially aliased and probably do not represent more than a snapshot of outgoing wave generation (report in preparation). However, taken collectively, these data can be used to generate predictive curves for the average ground motion as a function of scaled range for contained underground explosions.

Accelerometer stations are named with a code as follows: three letters for the first three letters of the event name; followed by two letters to indicate the type of measurement (GM for J-8 stations; GR for GRMPY stations; and SG for extended-surface-accelerometer stations); followed by a number for the station, followed by a letter, normally "A," representing a single station. The letters B, C, or D were used if there were multiple sensors at the same location, or, if there were multiple stations on a single portable DAS (e.g., Misty Echo, Metropolis, Mineral Quarry, and Bexar). In the last case, refer to the data tables for the event to find the location of each station. The gauge-data plots included in this report have two additional letters immediately following the station name, Z for the vertical component and A, V, or D for acceleration, velocity, and displacement, respectively. Therefore, MISGR1AZA would denote the vertical acceleration from station 1A of the GRMPY array on Misty Echo.

Two seconds of record are displayed for each station; the start time of the display for each station may have been shifted so that the signal onset is in the first third of the record. All times presented are from explosion zero time, in seconds.

The SIG data are presented as tables with location number, azimuth, and distance from SGZ, azimuth and distance moved, and any observational comments. For Metropolis we present one of many ways that these data may be portrayed for analysis. Azimuths have been corrected to true north.

4. Event Data

The following pages contain a brief description of the experiment setups and data for ten events: Misty Echo, Texarkana, Tulia, Contact, Amarillo, Hornitos, Metropolis, Mineral Quarry, Bexar, and Junction.

4.1. Misty Echo (U12n.23)

Experiment design. The Area 12 tunnel event Misty Echo had an array of 18 surface ground motion stations: 8 GRMPY near and around SGZ, all inside the predicted spall zone, and 10 extended ground-motion stations (from just inside to well beyond the edge of predicted spall), fielded by SMU and DNA/A (Fig. 1 and Table 1). Figure 2 (16 pages) contains the data traces for the accelerometer data.

GRMPY results. All GRMPY stations recorded spall signals. Two of the ten ESA stations failed to record good data (3A and 9A). Of the remaining eight, four recorded spall signals (2A, 5A, 7A, and 13A).

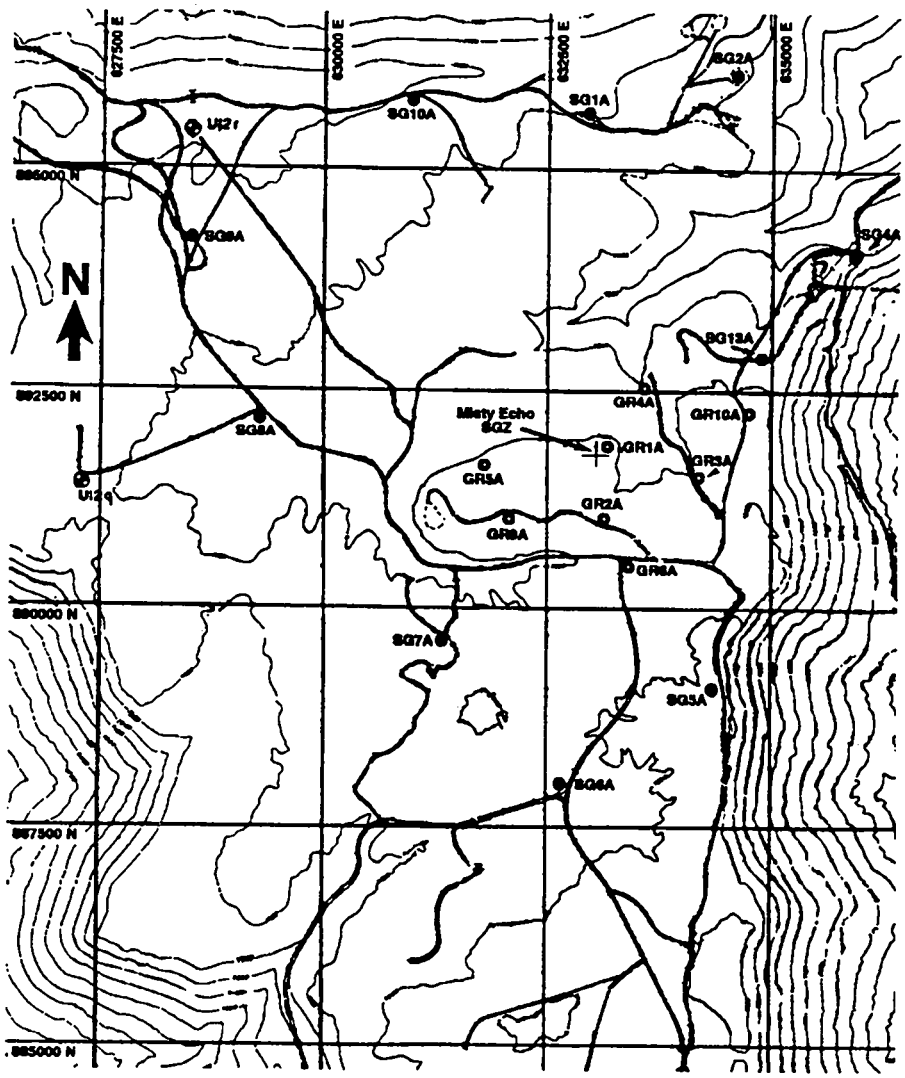
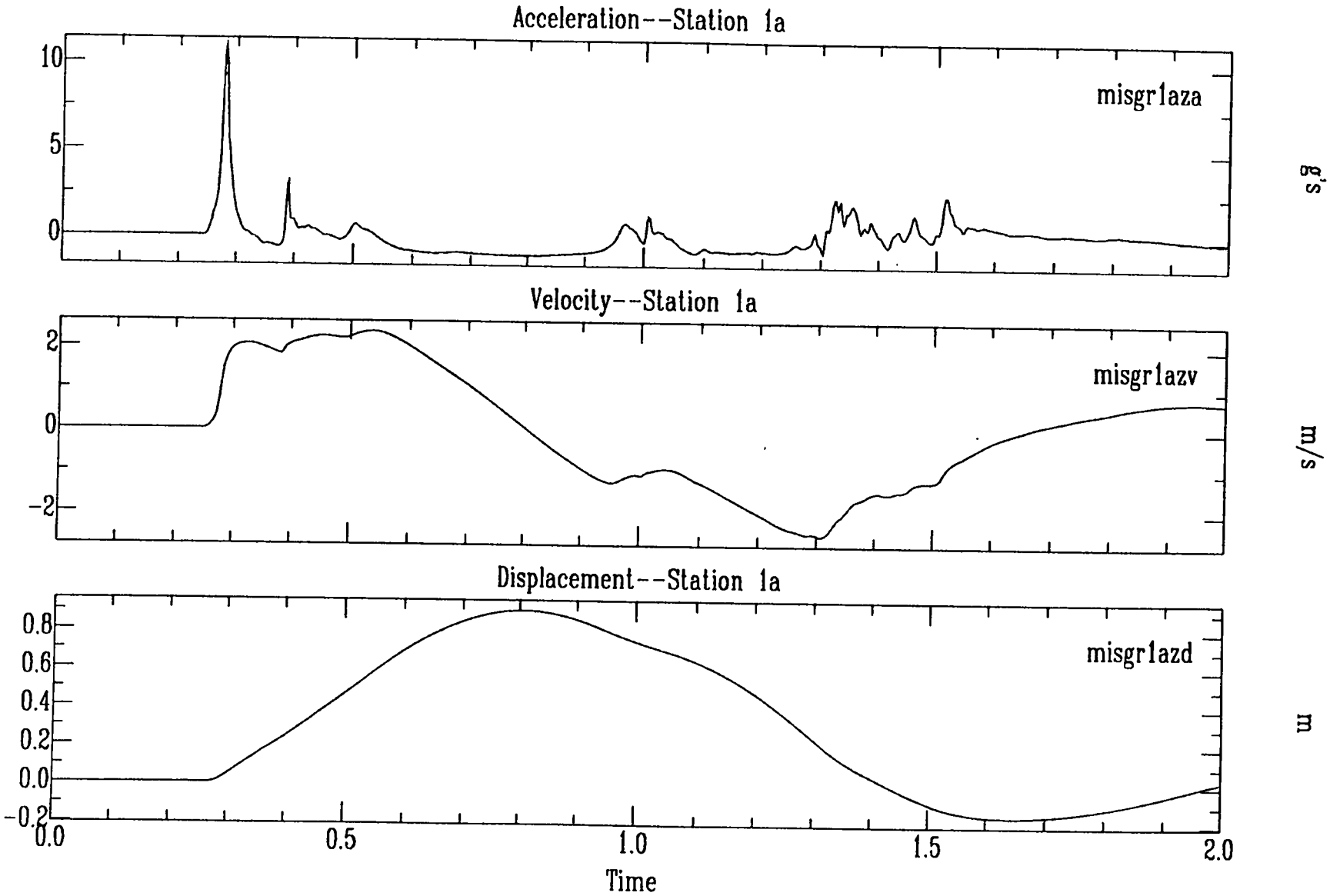


Fig. 1. Misty Echo station map.

Table 1. Misty Echo Ground-Motion Station Data

Station Name	Station Loc U12n.23	Accelerometer	Northing (m) 271809	Easting (m) 192992	Slant Range (m) DOB	TOA
MISGR1A	17 m N10E	25 g	271821	192996	400	0.247
MISGR2A	~200 m S	25 g	271570	192981	466	0.271
MISGR3A	~300 m N20E	25 g	271709	193314	523	0.192
MISGR4A	~300 m N20E	25 g	272042	193110	478	0.272
MISGR5A	~300 m W	25 g	271725	192520	625	0.36
MISGR6A	~370 m S10E	25 g	271415	193087	570	0.314
MISGR9A	~450 m S50W	25 g	271578	192659	569	0.364
MISGR10A	520 m N60E	25 g	271943	193482	647	0.388
MISSG1A	1180 m N3W	Terra Tec 5.28 g	272985	192930	1244	0.472
MISSG2A	1260 m N19E	Terra Tec 5.28 g	273000	193410	1324	0.288
MISSG4A	1085 m N50E	Terra Tec 5.28 g	272500	193830	1157	0.499
MISSG5A	880 m S23E	Terra Tec 5.28 g	271000	193340	967	0.348
MISSG6A	1140 m S8W	Terra Tec 5.28 g	270680	192825	1209	0.122
MISSG7A	875 m S42W	Terra Tec 5.28 g	271160	192405	962	0.408
MISSG8A	1200 m N85W	Terra Tec 5.28 g	271910	191795	1266	0.2
MISSG9A	1615 m N62W	Terra Tec 5.28 g	272560	191565	1661	0
MISSG13A	630 m N57E	Terra Tec 5.28 g	272150	193520	745	0.44

Misty Echo Surface Ground Motion



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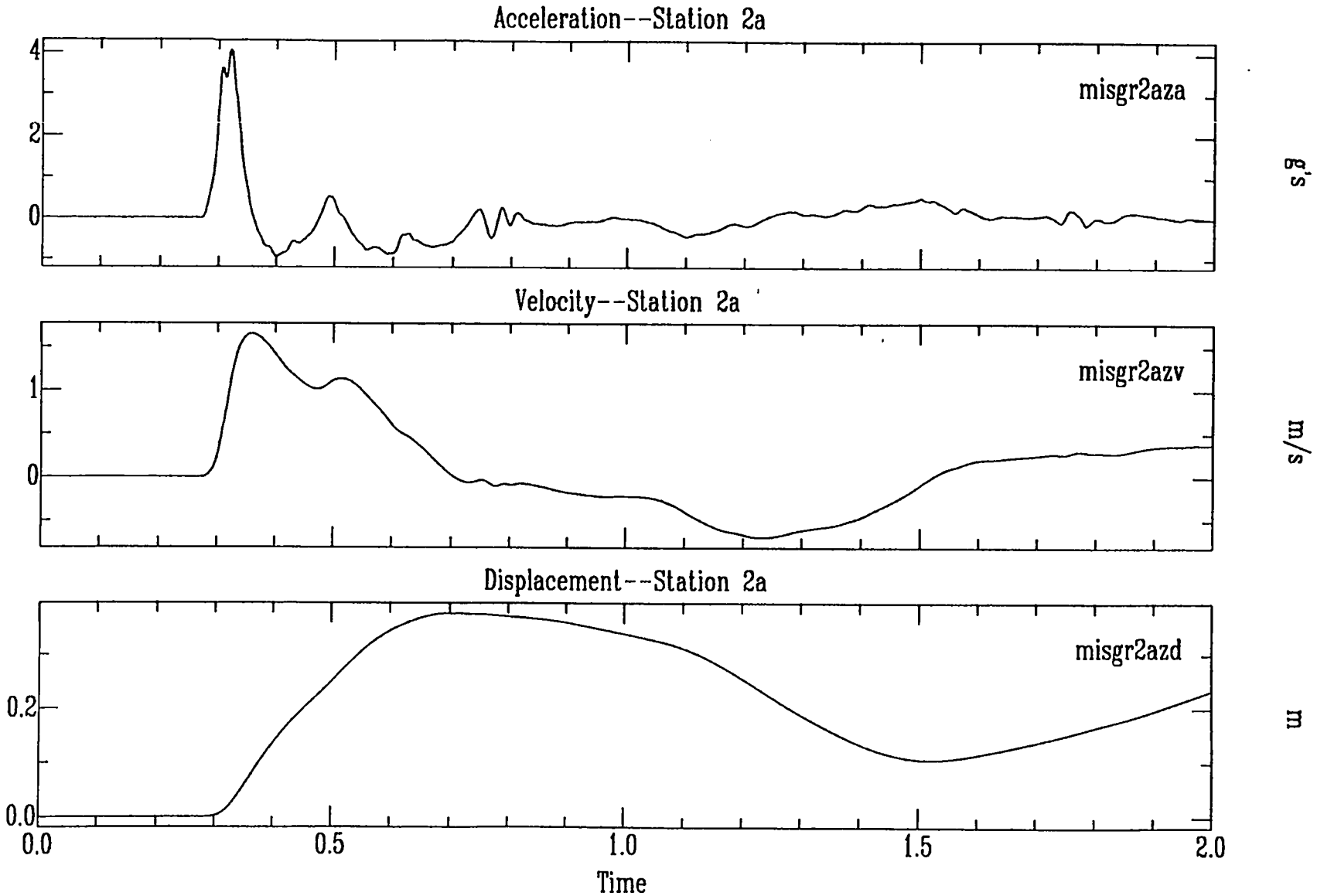

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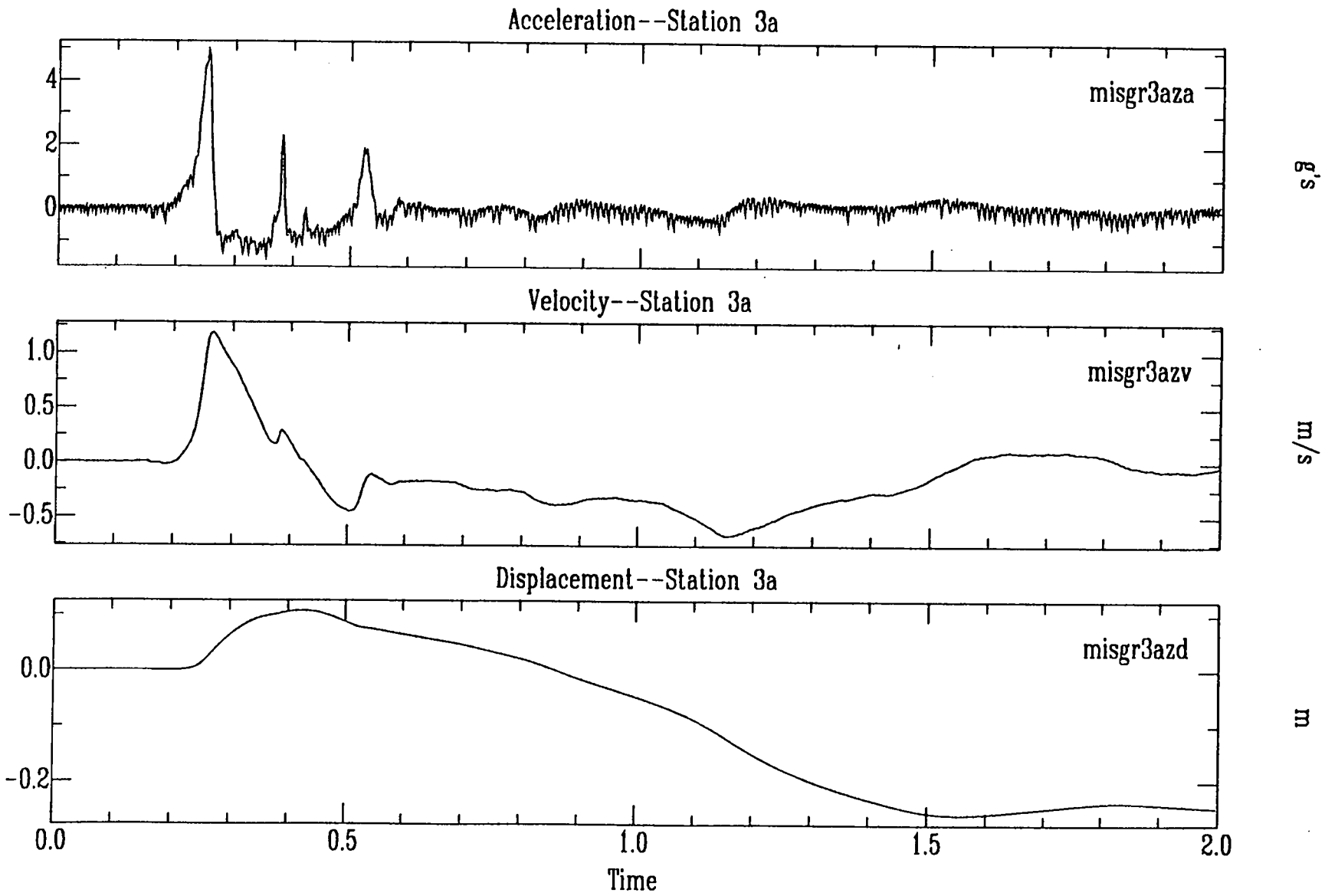

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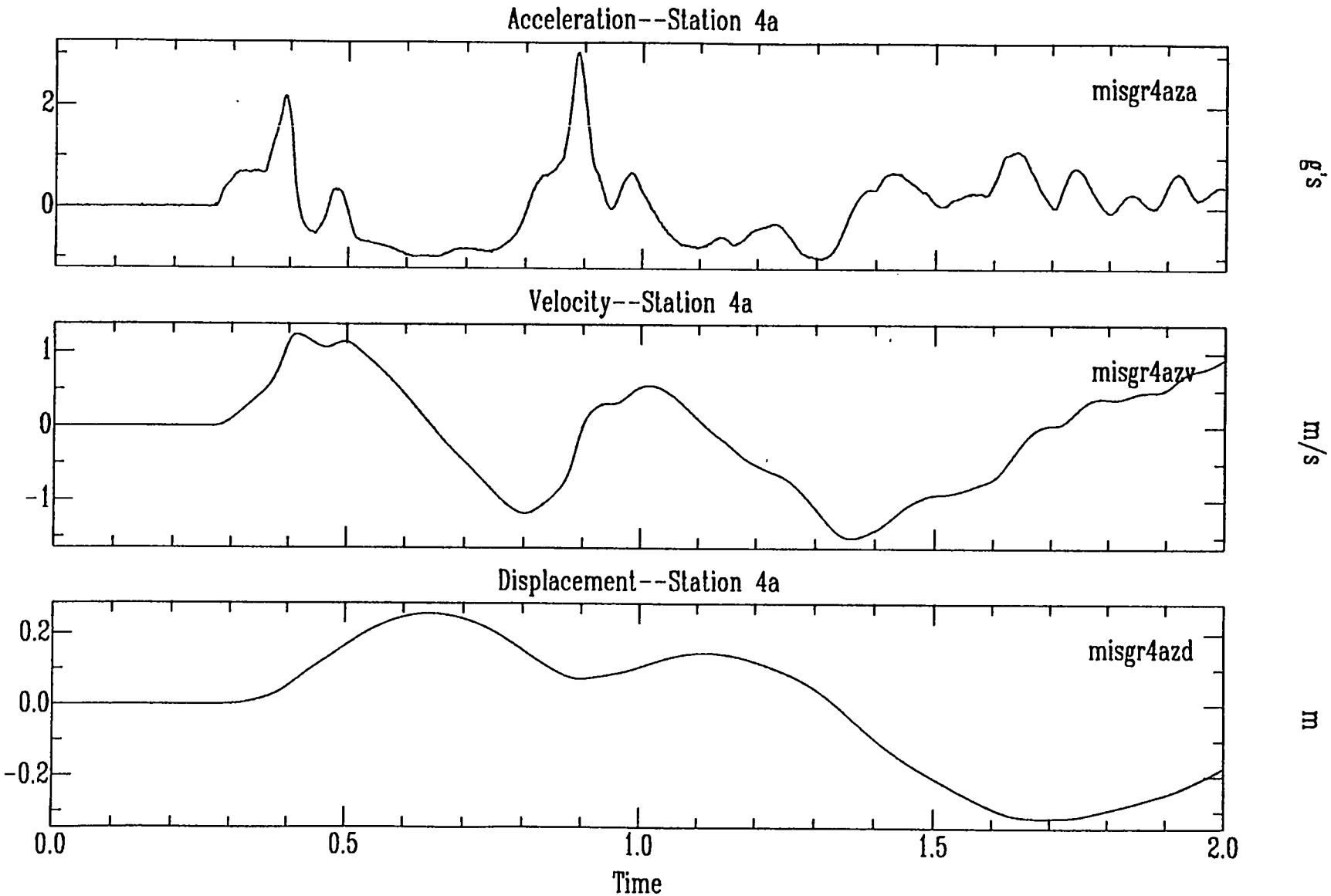

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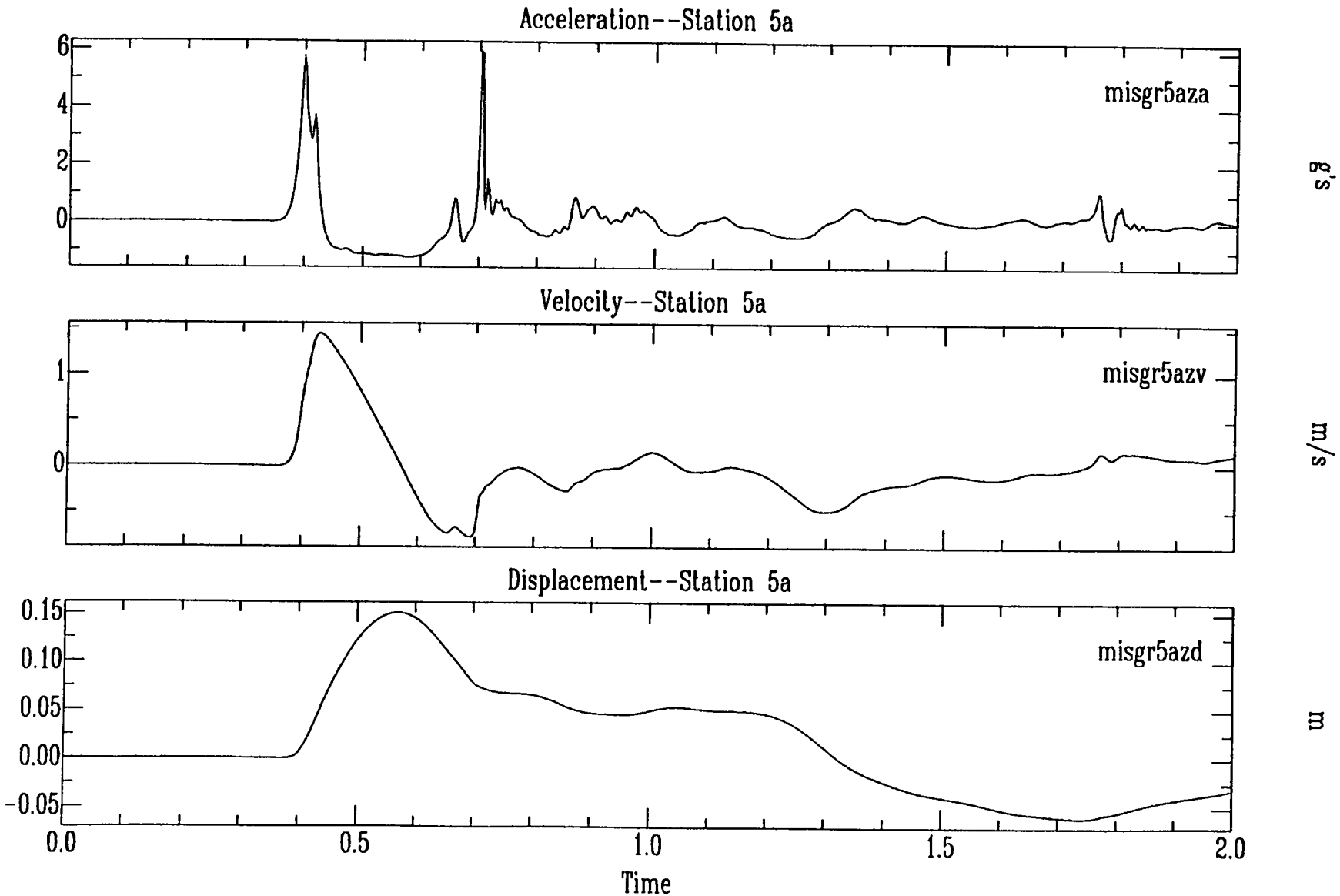

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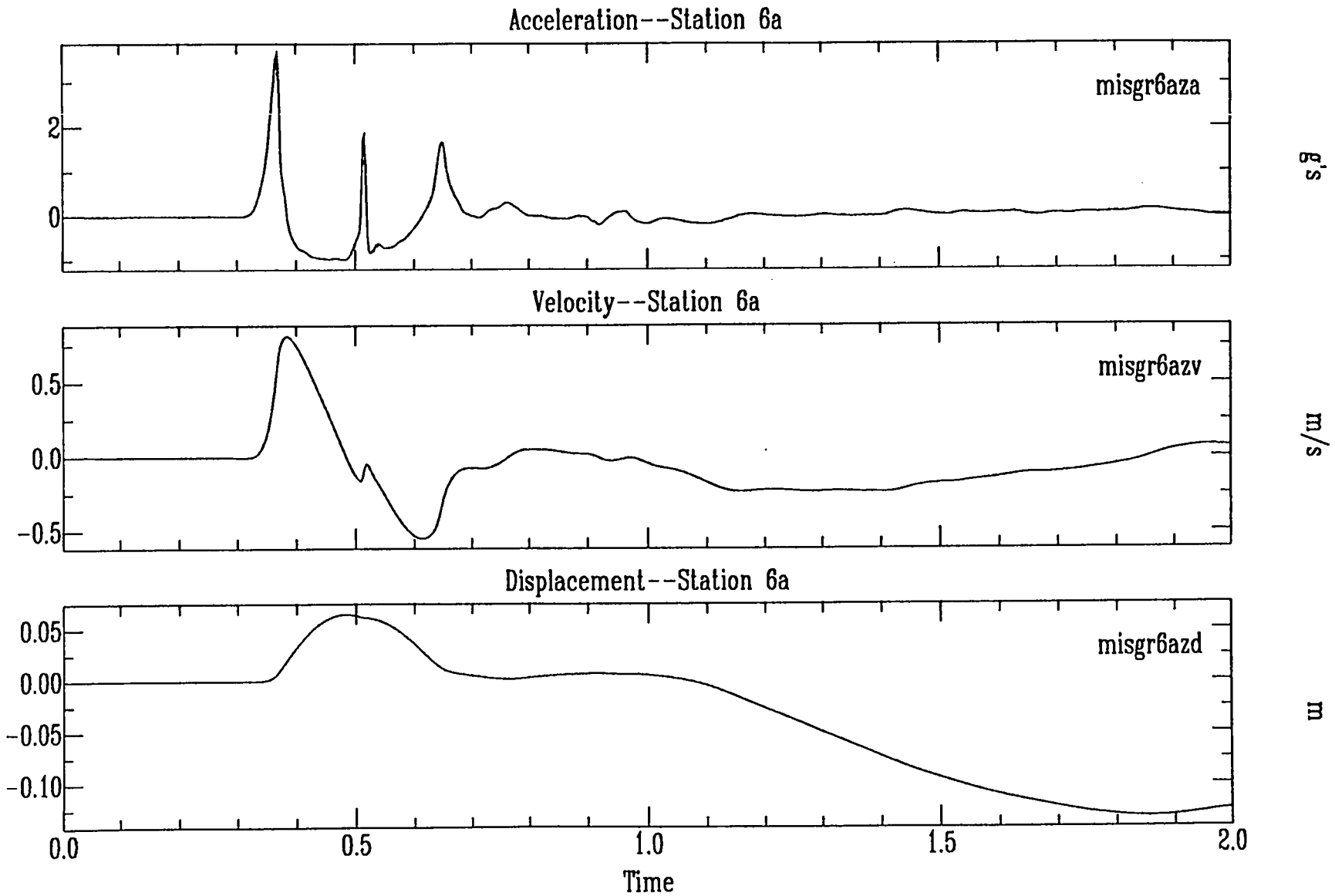

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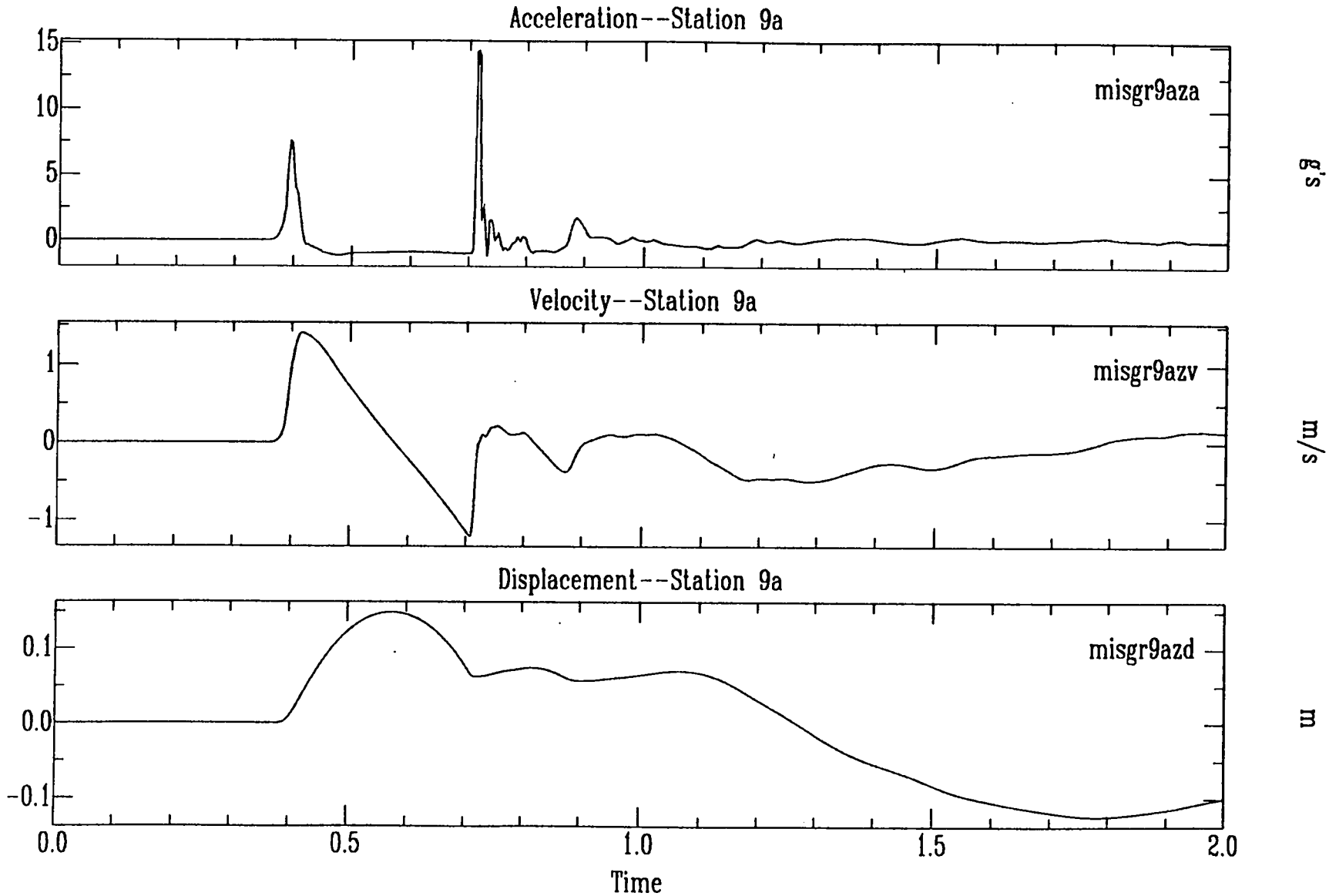

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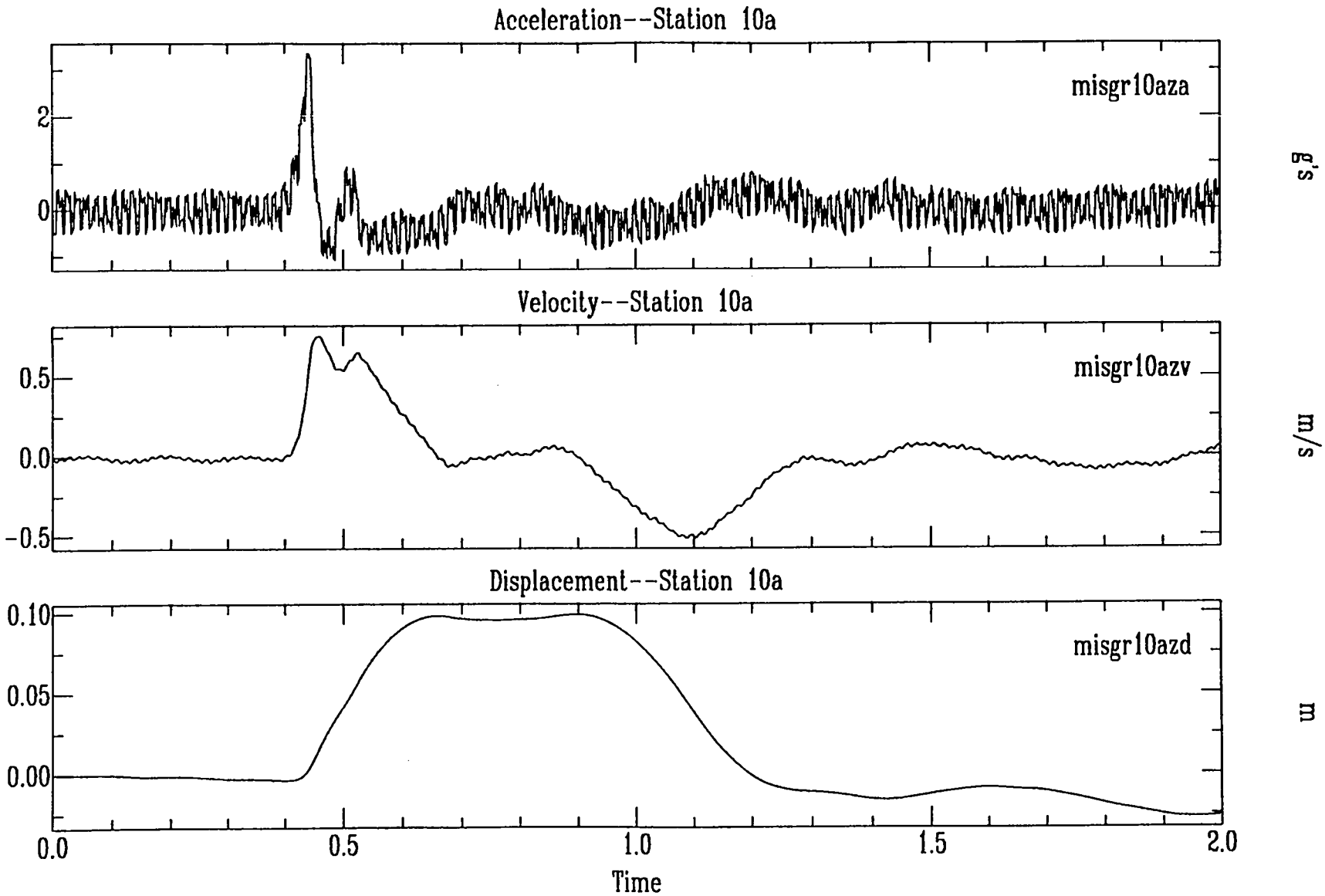

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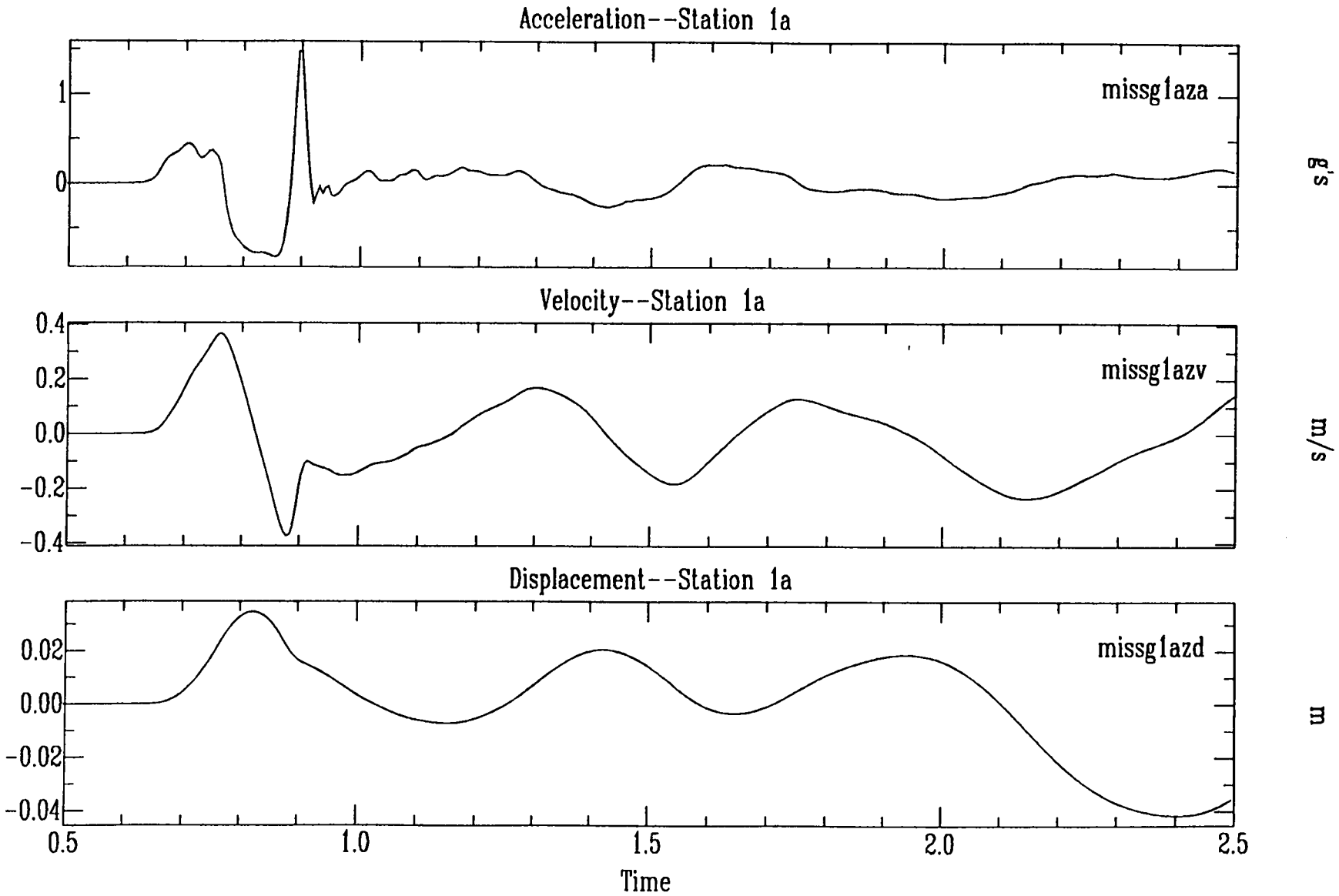

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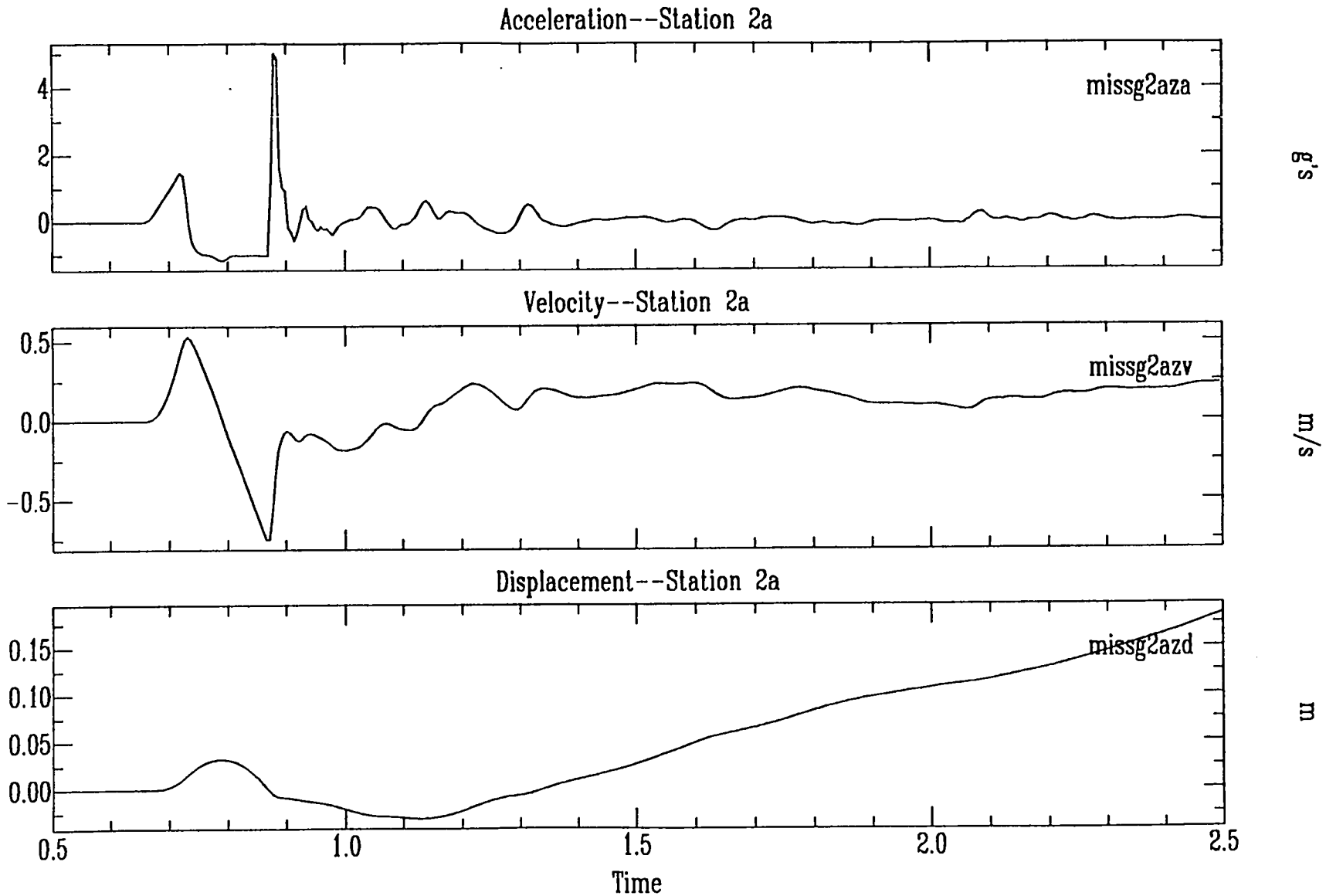

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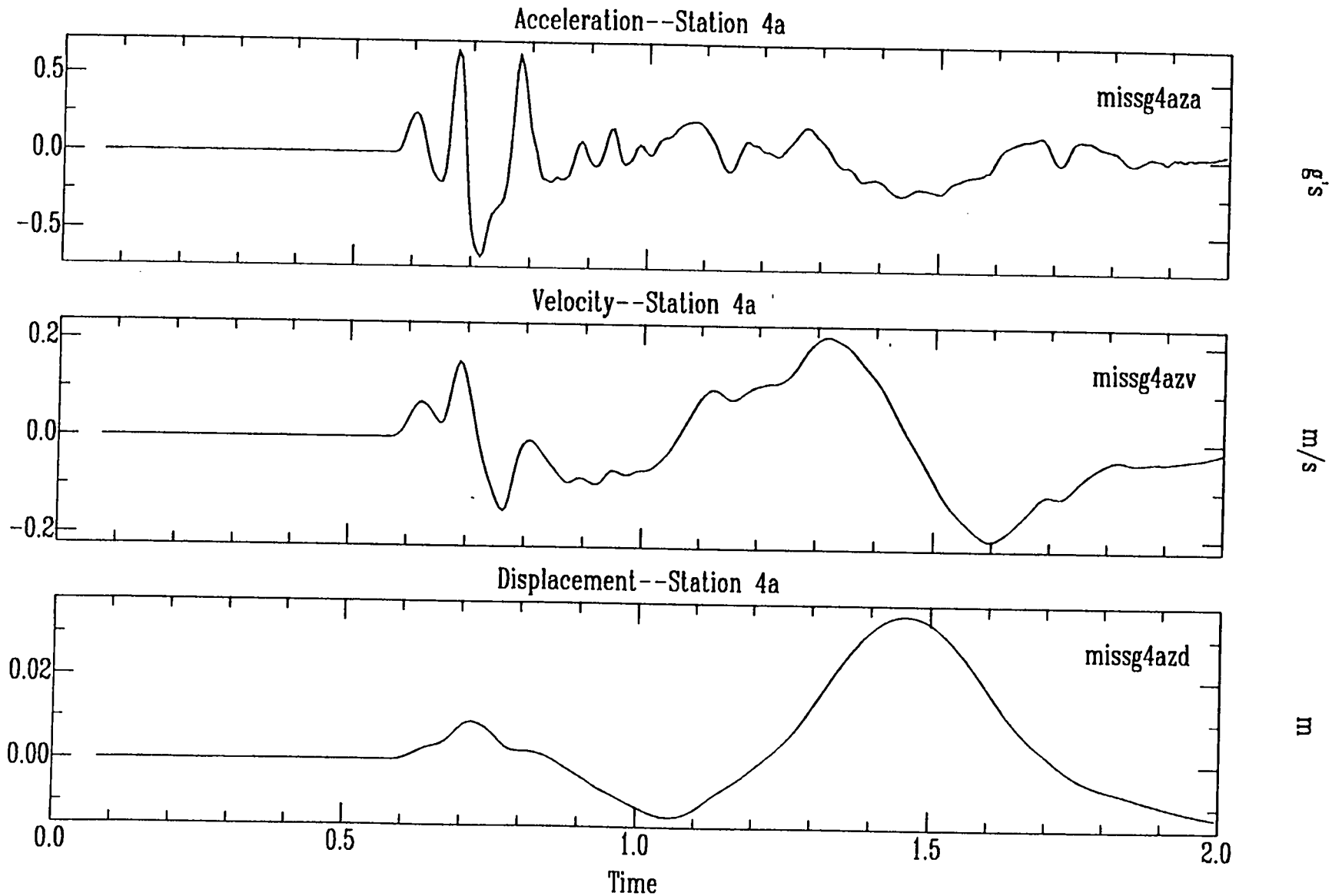

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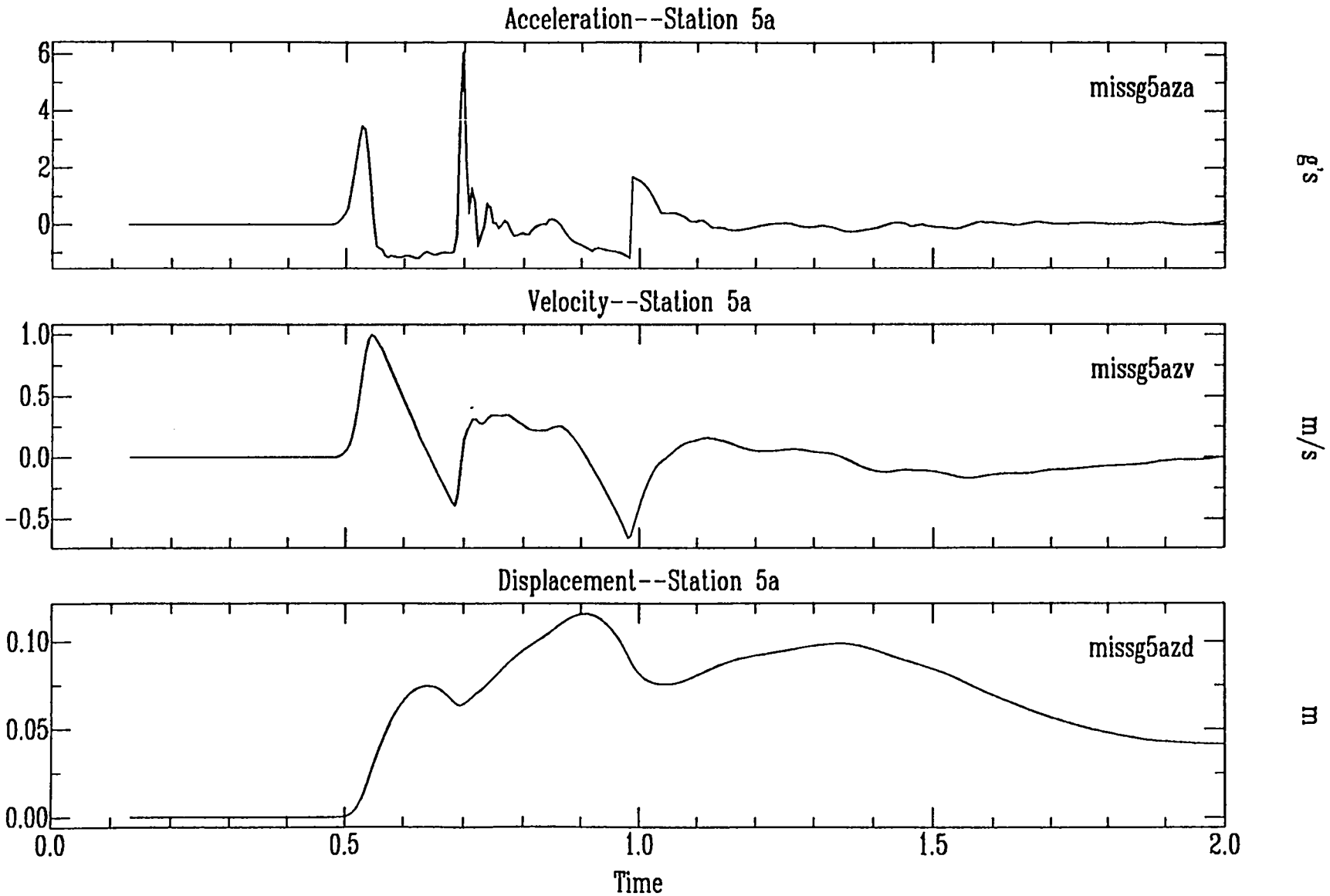

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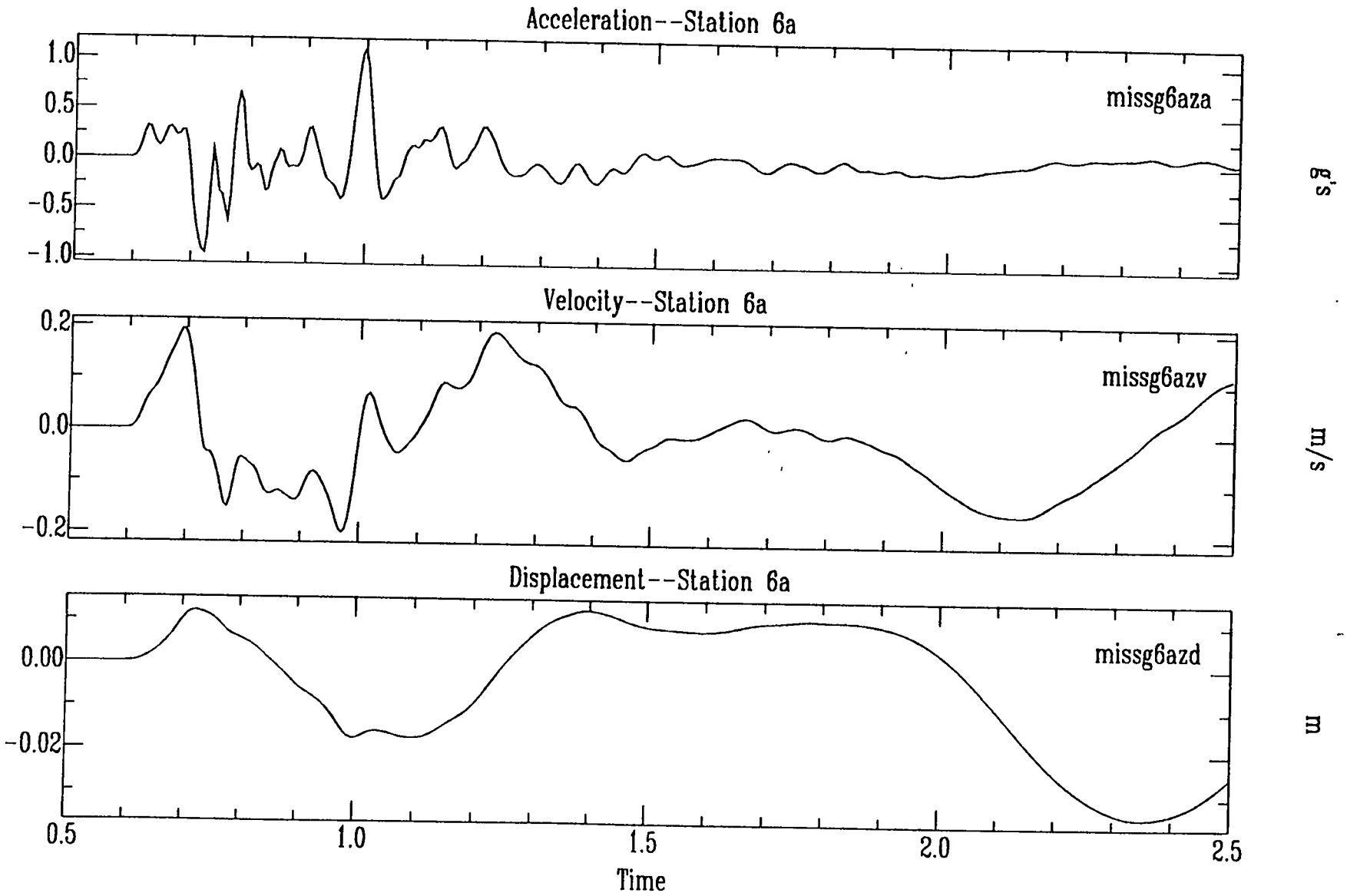

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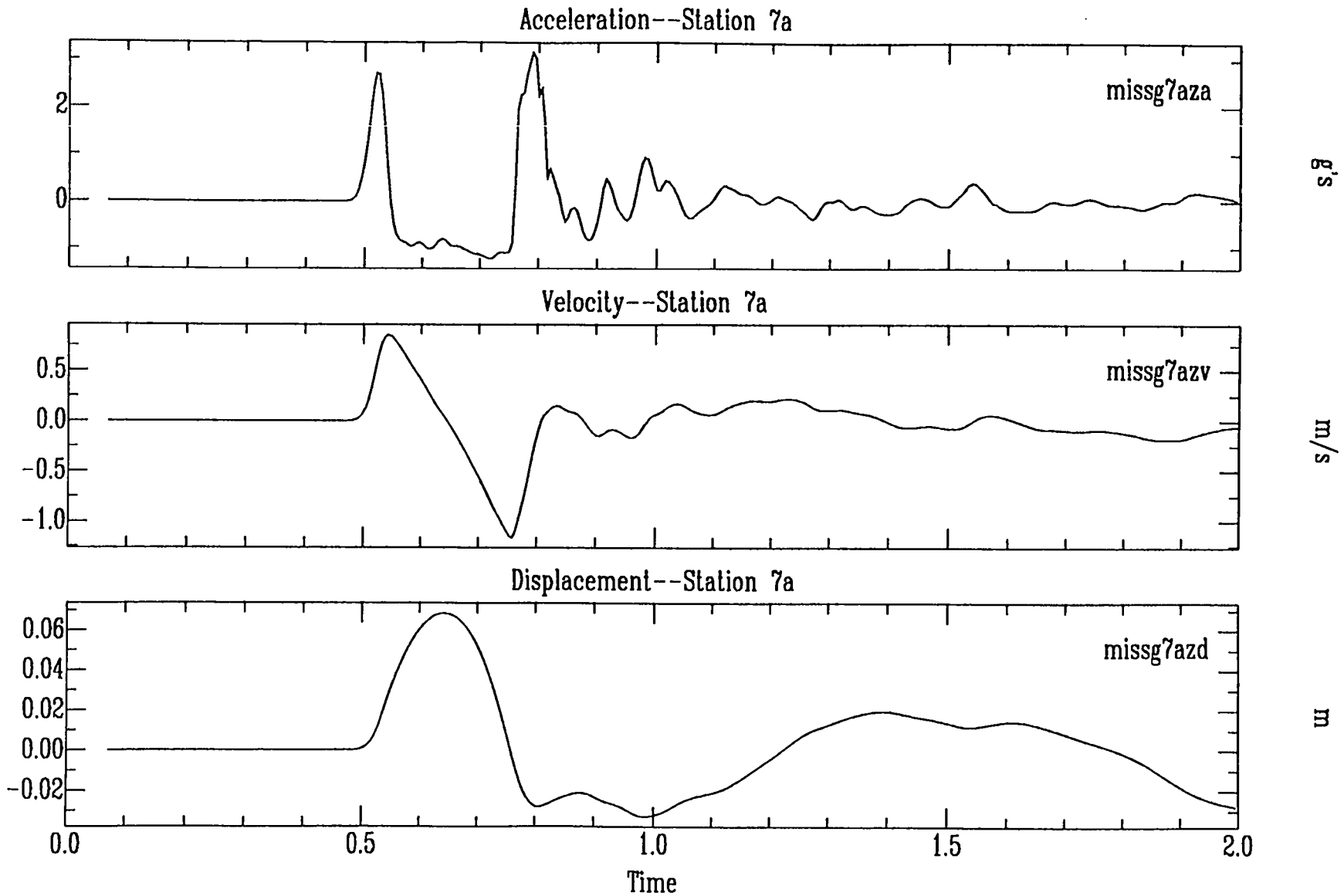

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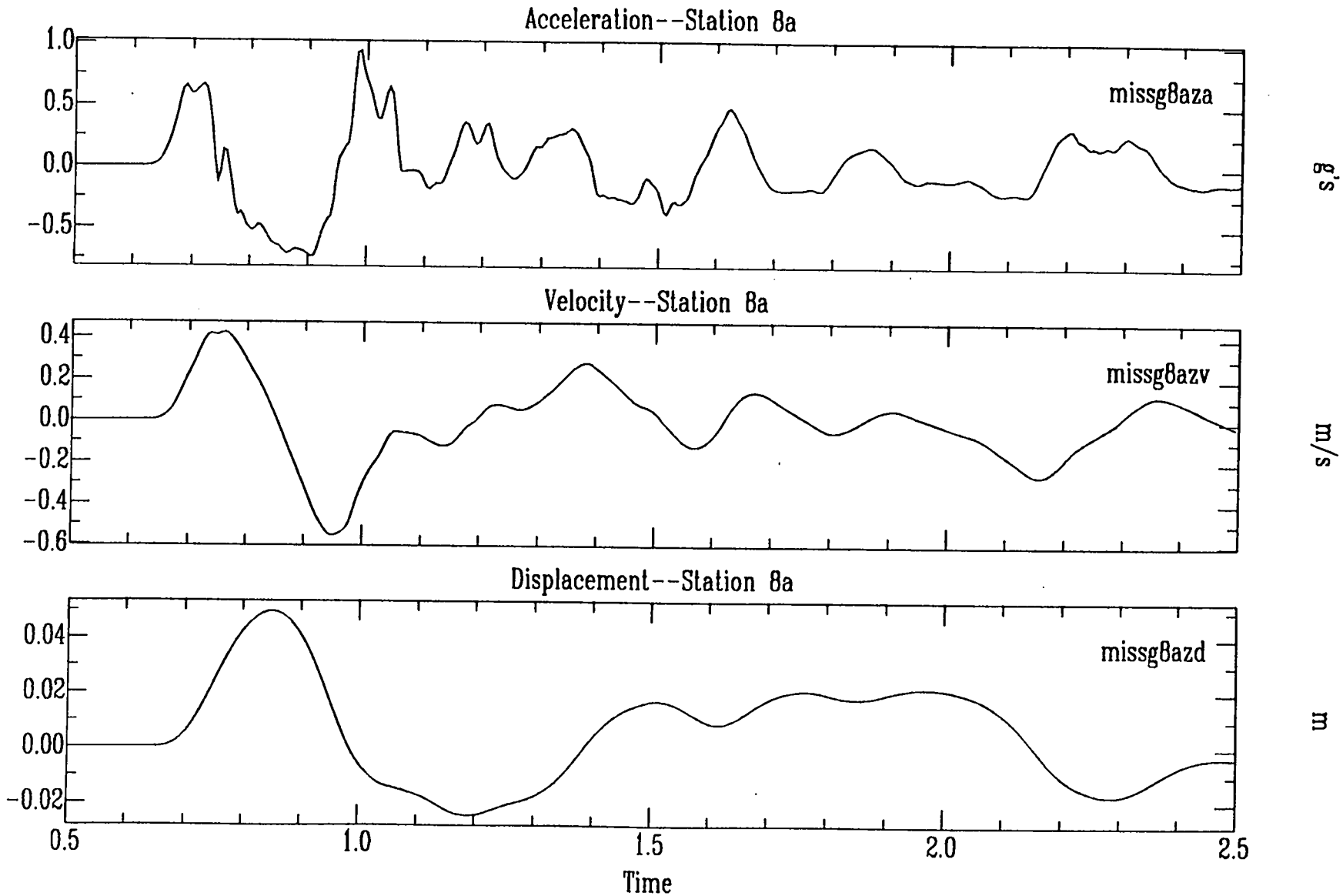

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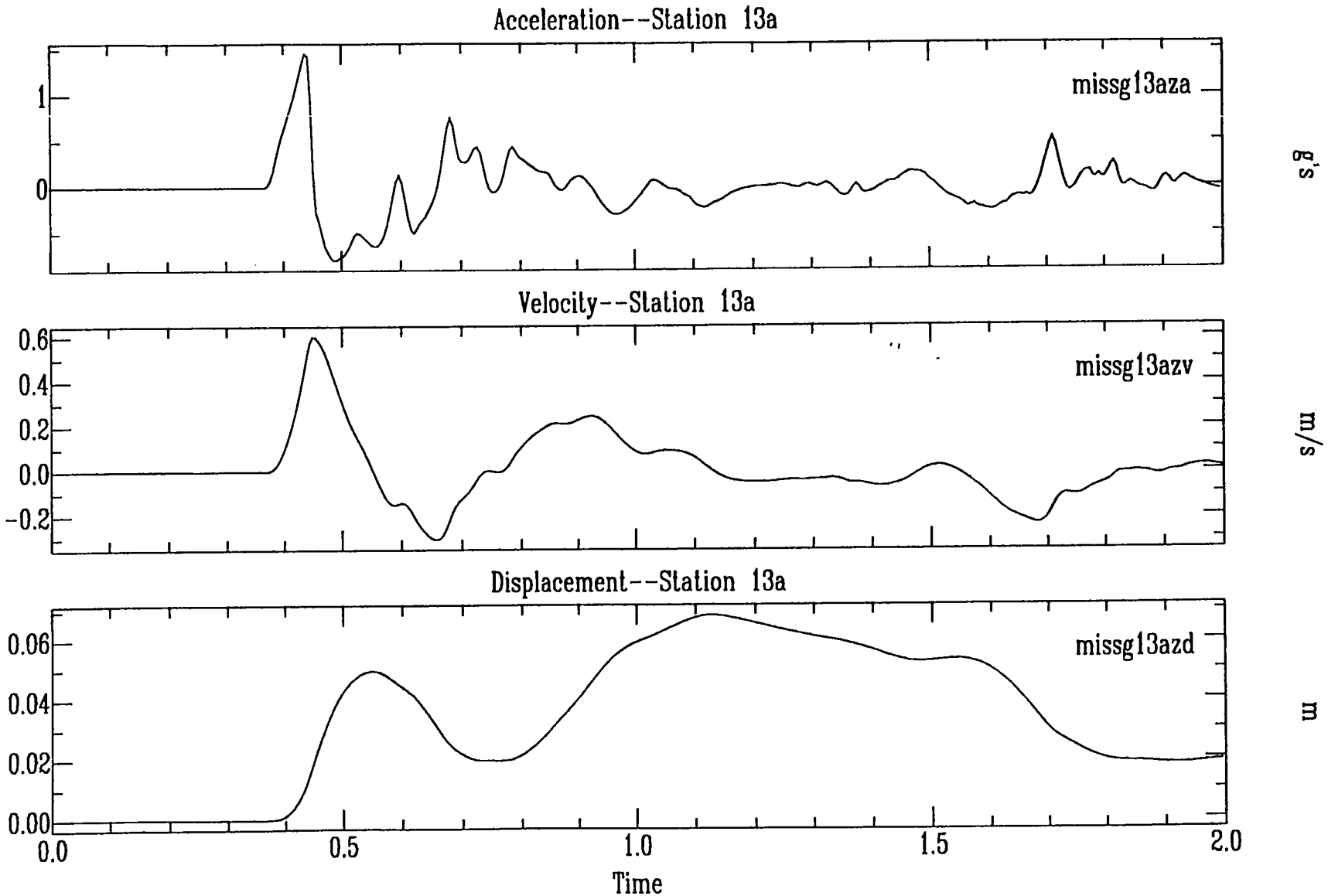


4.2. Texarkana (U7ca).

Experimental design. The Texarkana event had a surface array of 10 J-8 stations (including three near SGZ and two at the trailer park) and four GRMPY stations, all of which were within the predicted spall zone (Fig. 3 and Table 2).

Results: The J-8 data were originally reported out in March 1989 (Memo J-8-89-58, R. S. Fitzhugh to F. N. App). All stations worked properly and all recorded spall signals. Figure 4 (14 pages) contains the station data traces for the accelerometer data.

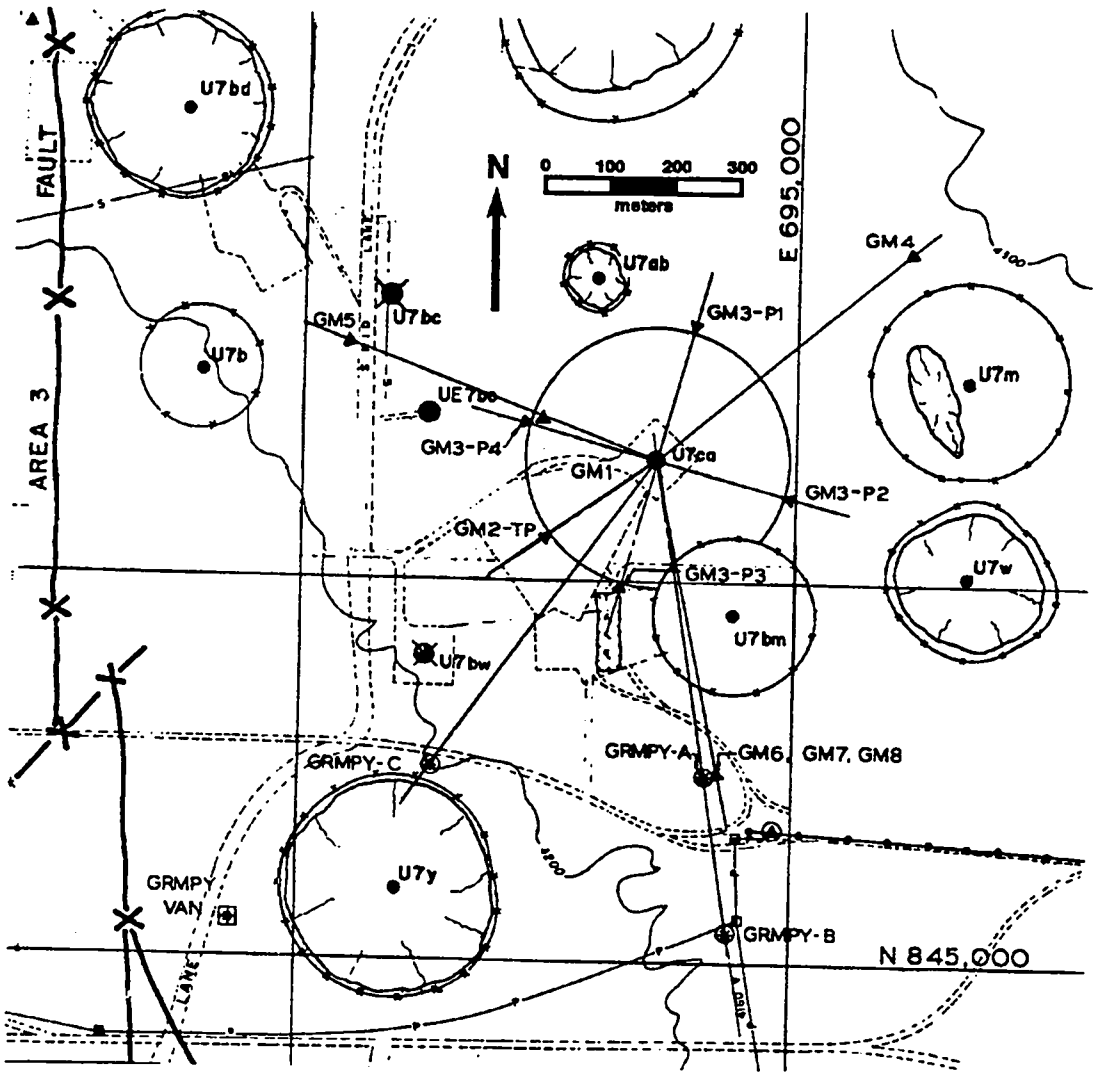
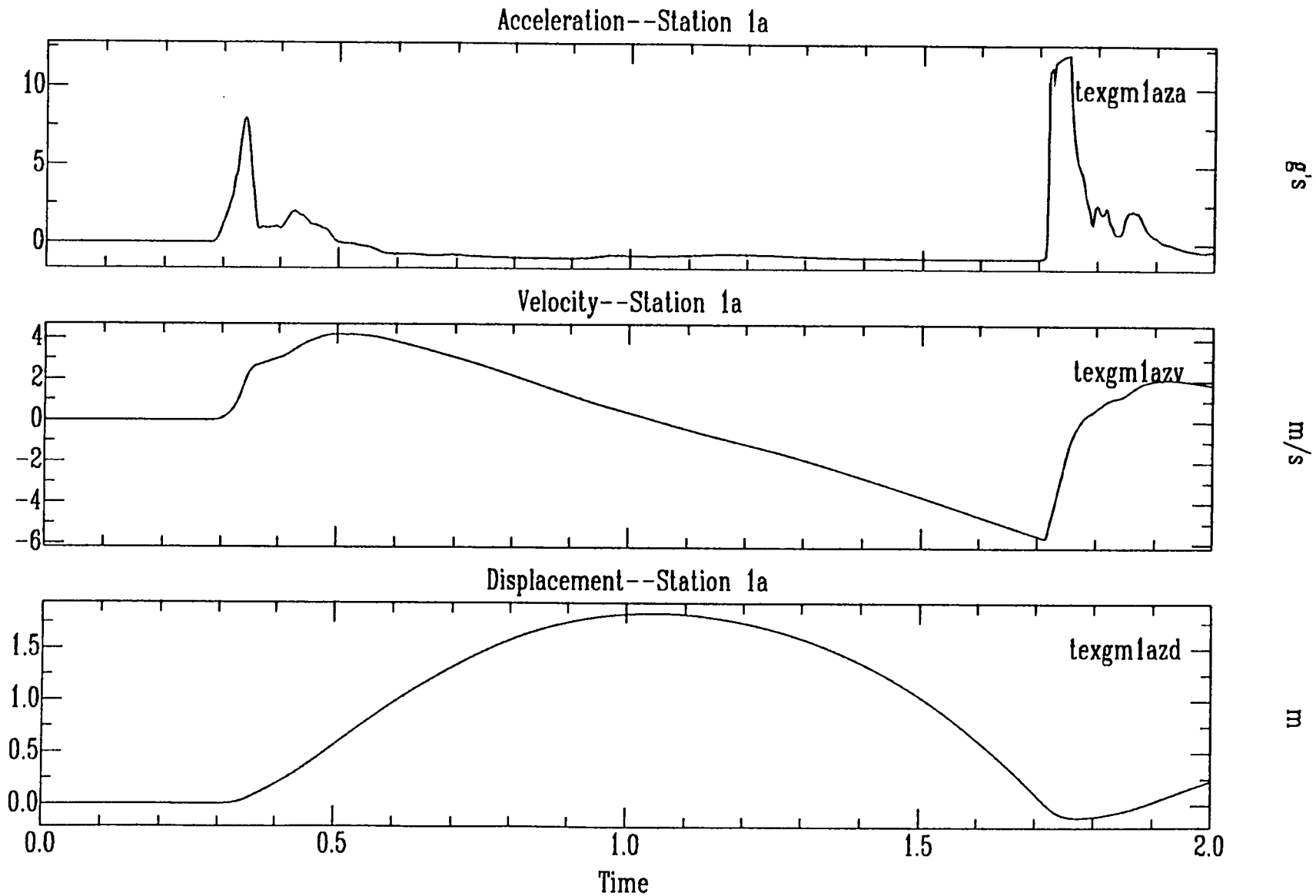


Fig. 3. Ground-motion-measurement array for Texarkana (U7ca).

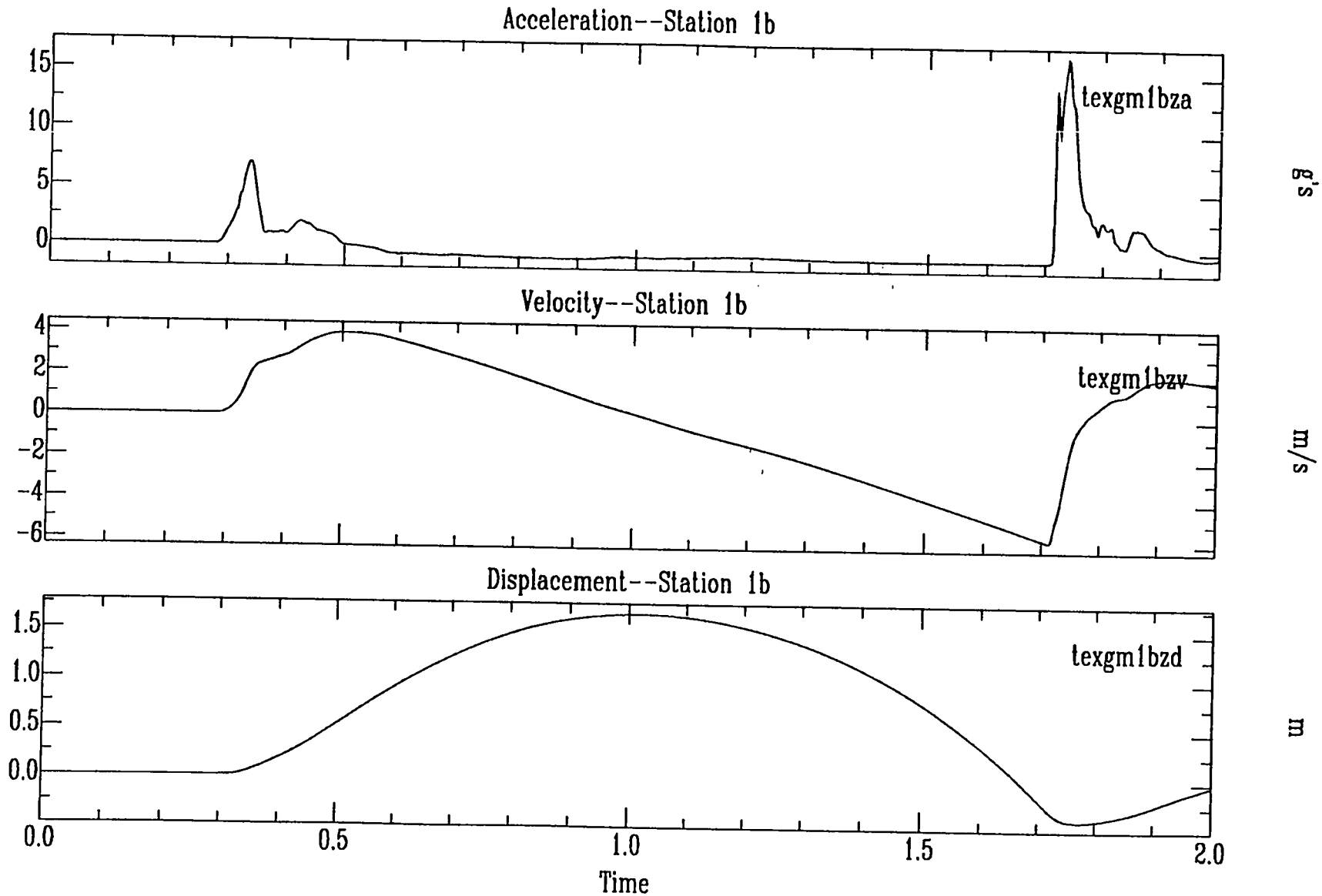
Table 2. Texarkana Ground-Motion Station Data

Station Name	Location U7ca	Accelerometer	Northing (m) 258348	Easting (m) 211623	Slant Range 503 (m) DOB	TOA
TEXGM1A	15 m S43W	Endevco 10 g	258338	211612	503	0.281
TEXGM1B	15 m S43W	Endevco 25 g	258338	211612	503	0.281
TEXGM1C	15 m S43W	Endevco 25 g	258338	211612	503	0.28
TEXGM2A	203 m S51W	Endevco 25 g	258222	211464	542	0.309
TEXGM2B	203 m S51W	Endevco 25 g	258222	211464	542	0.309
TEXGM4A	503 m N50E	Endevco 25 g	258672	212007	711	0.306
TEXGM5A	503 m N70W	Endevco 25 g	258520	211150	712	0.422
TEXGM6A	503 m S10E	Endevco 25 g	257853	211709	711	0.407
TEXGM7A	503 m S11E	Endevco 25 g	257854	211714	711	0.408
TEXGM8A	503 m S11E	Endevco 25 g	257855	211718	711	0.408
TEXGR9A	503 m S09E	25 g	257852	211701	711	0.398
TEXGR10A	594 m S35W	25 g	257862	211282	778	0.449
TEXGR11A	975 m S42W	25 g	257618	210976	1098	0.699
TEXGR12A	975 m S42W	25 g	260666	210976	1098	0.635

Texarkana Surface Ground Motion



Texarkana Surface Ground Motion



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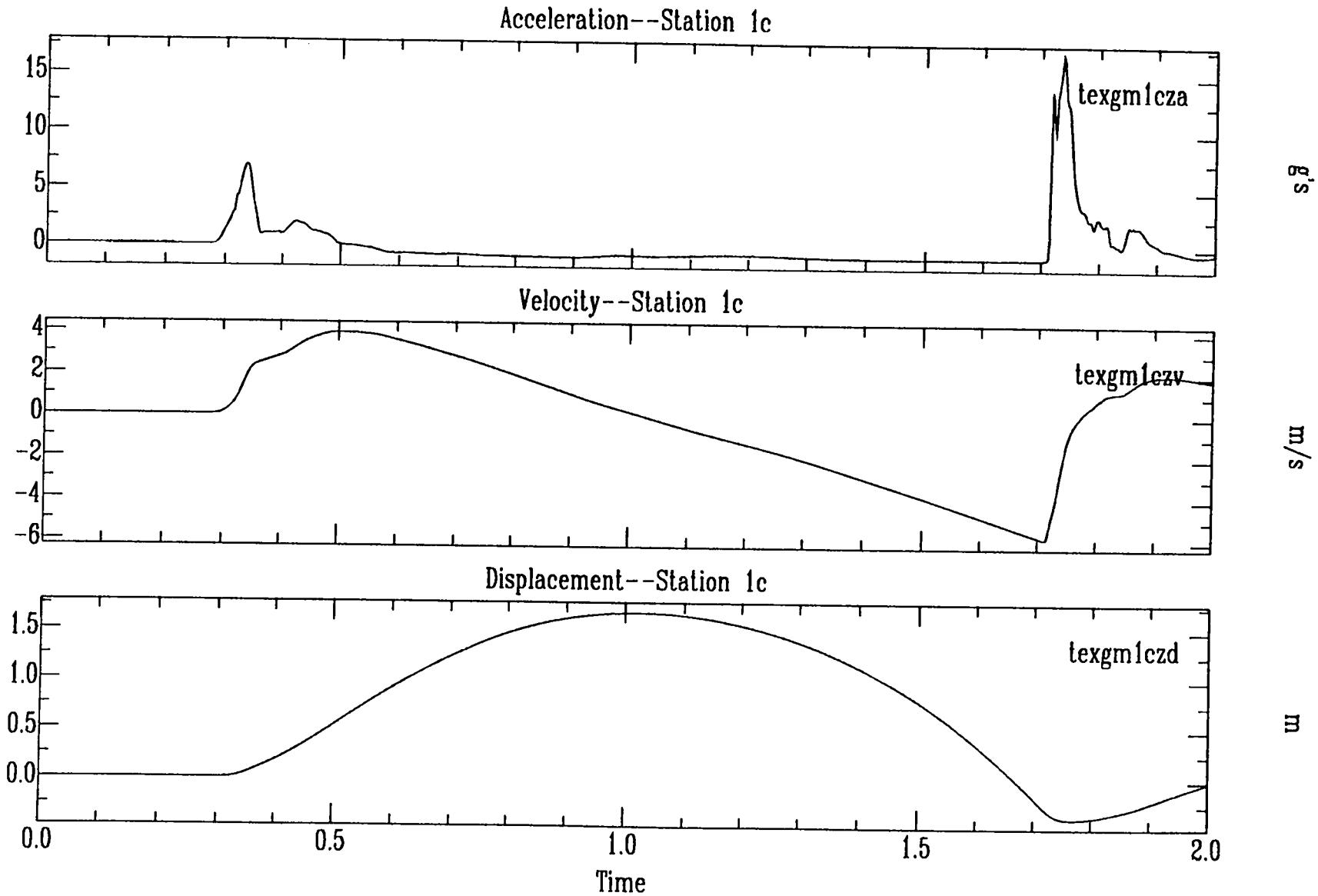

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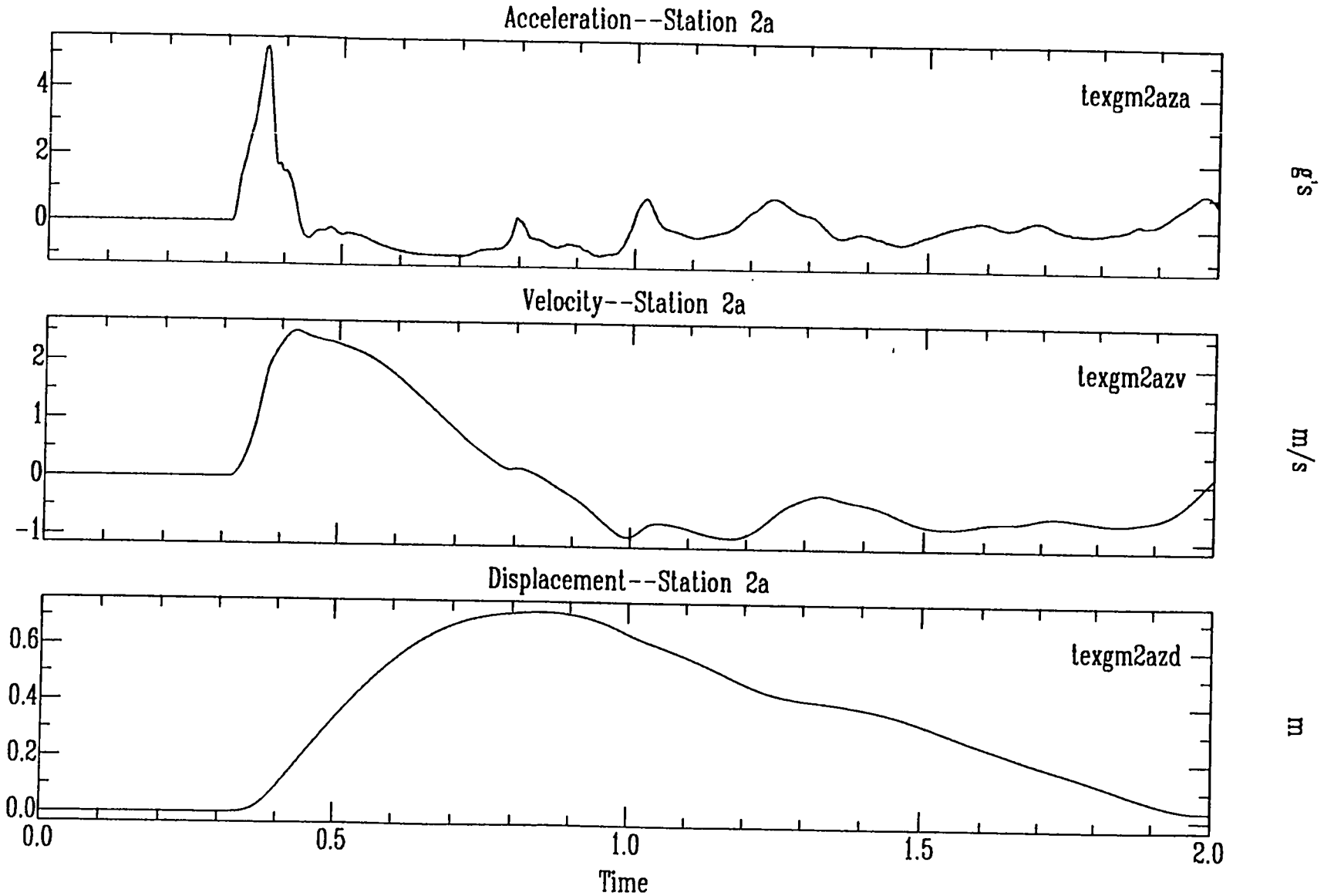

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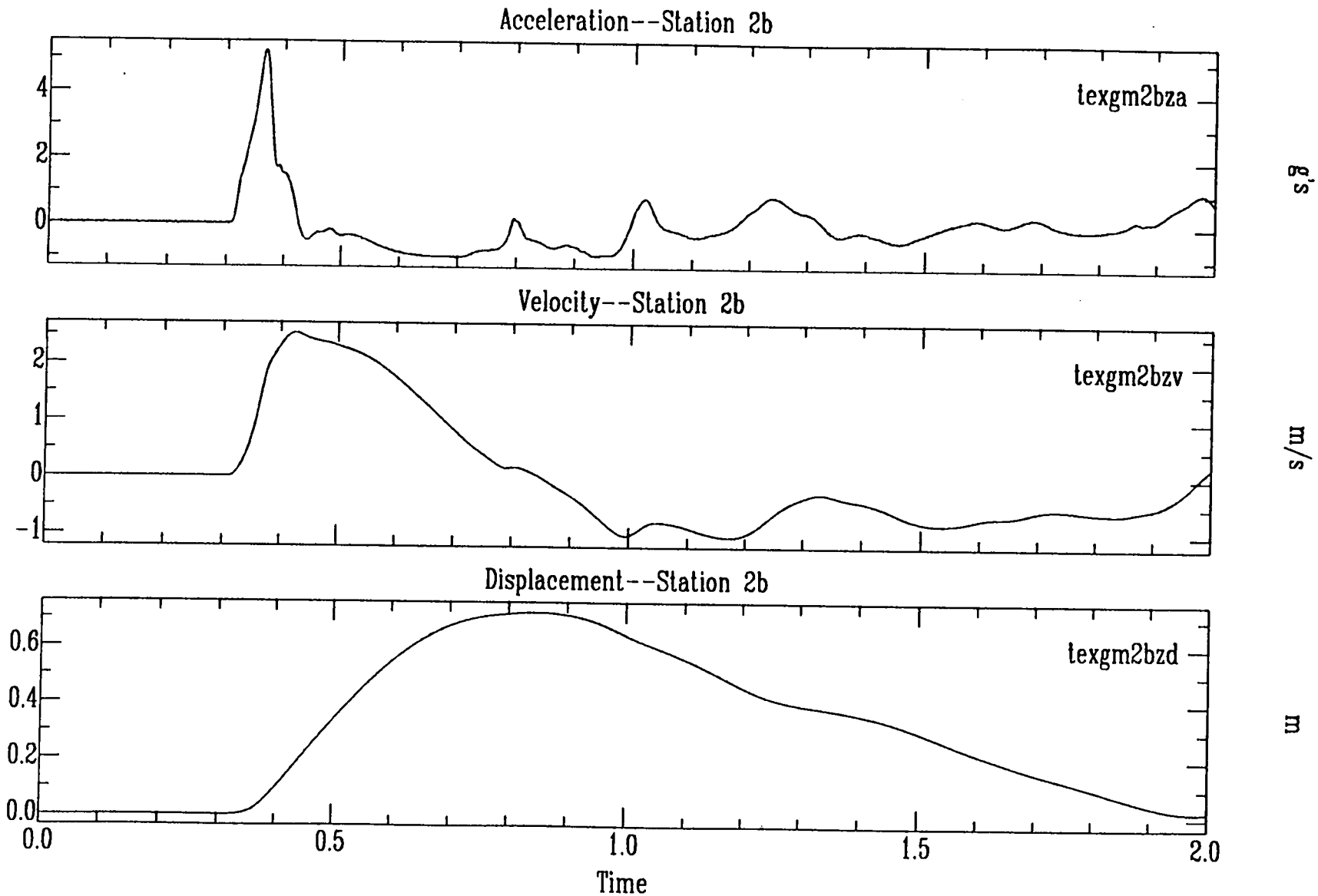

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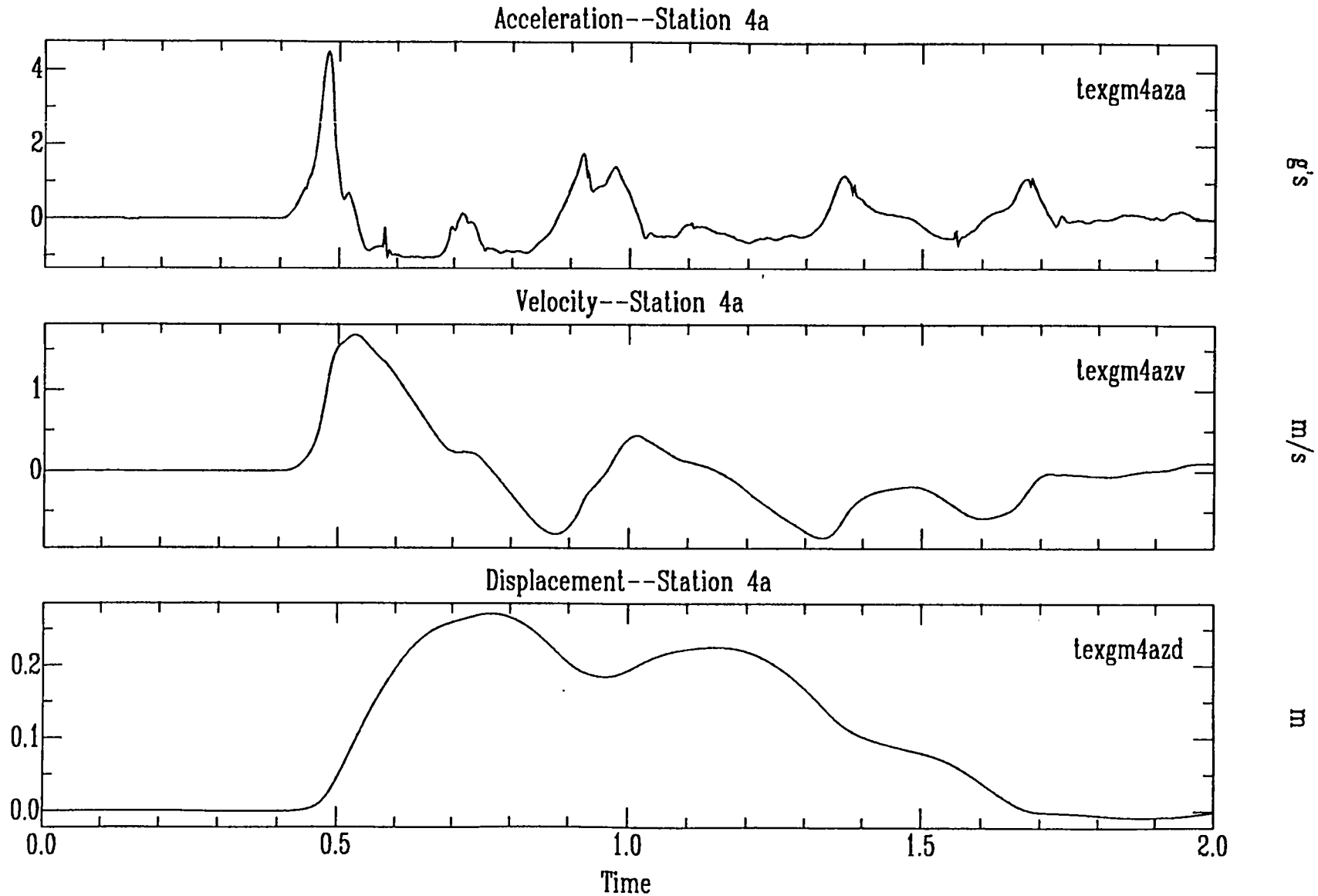

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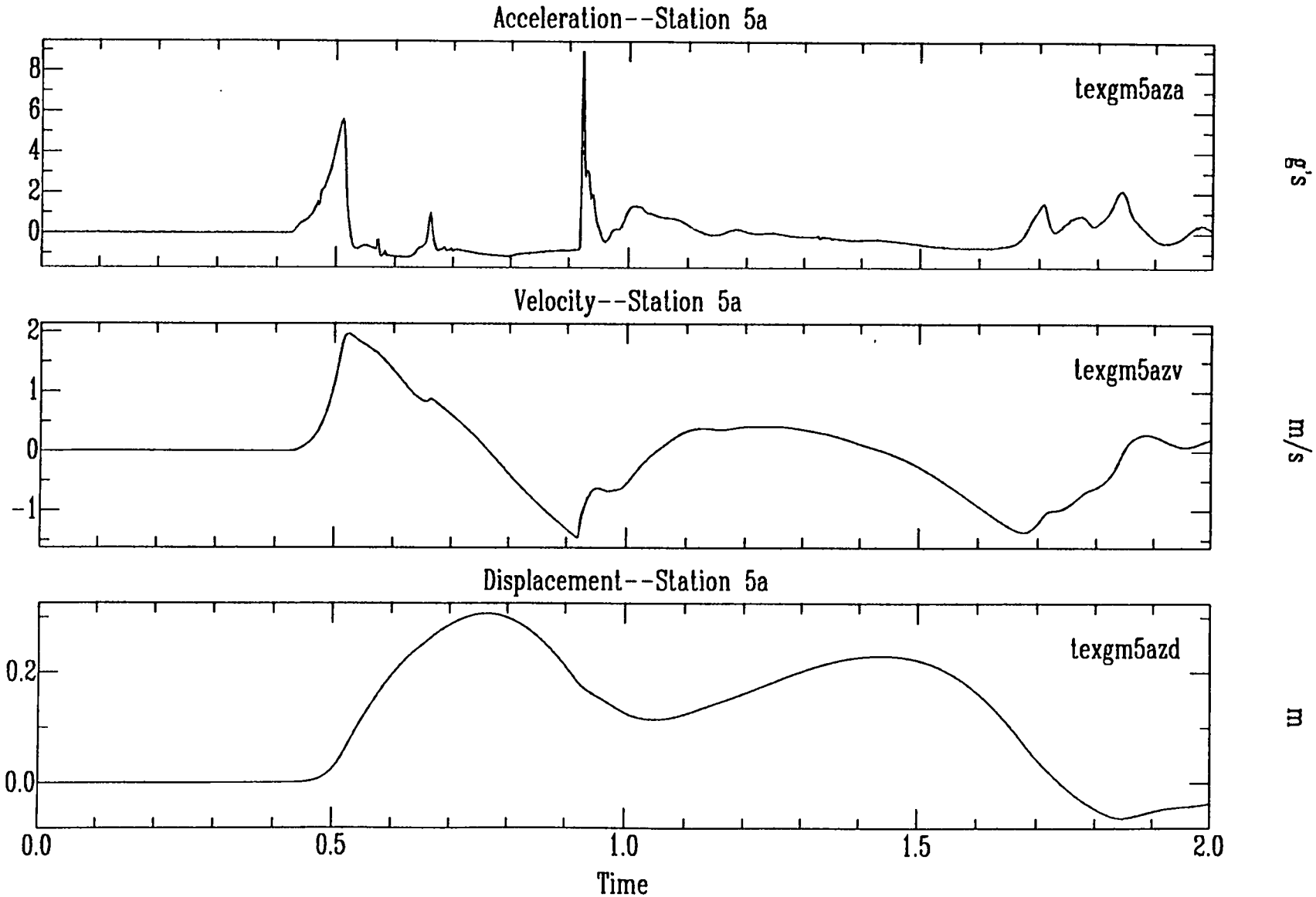

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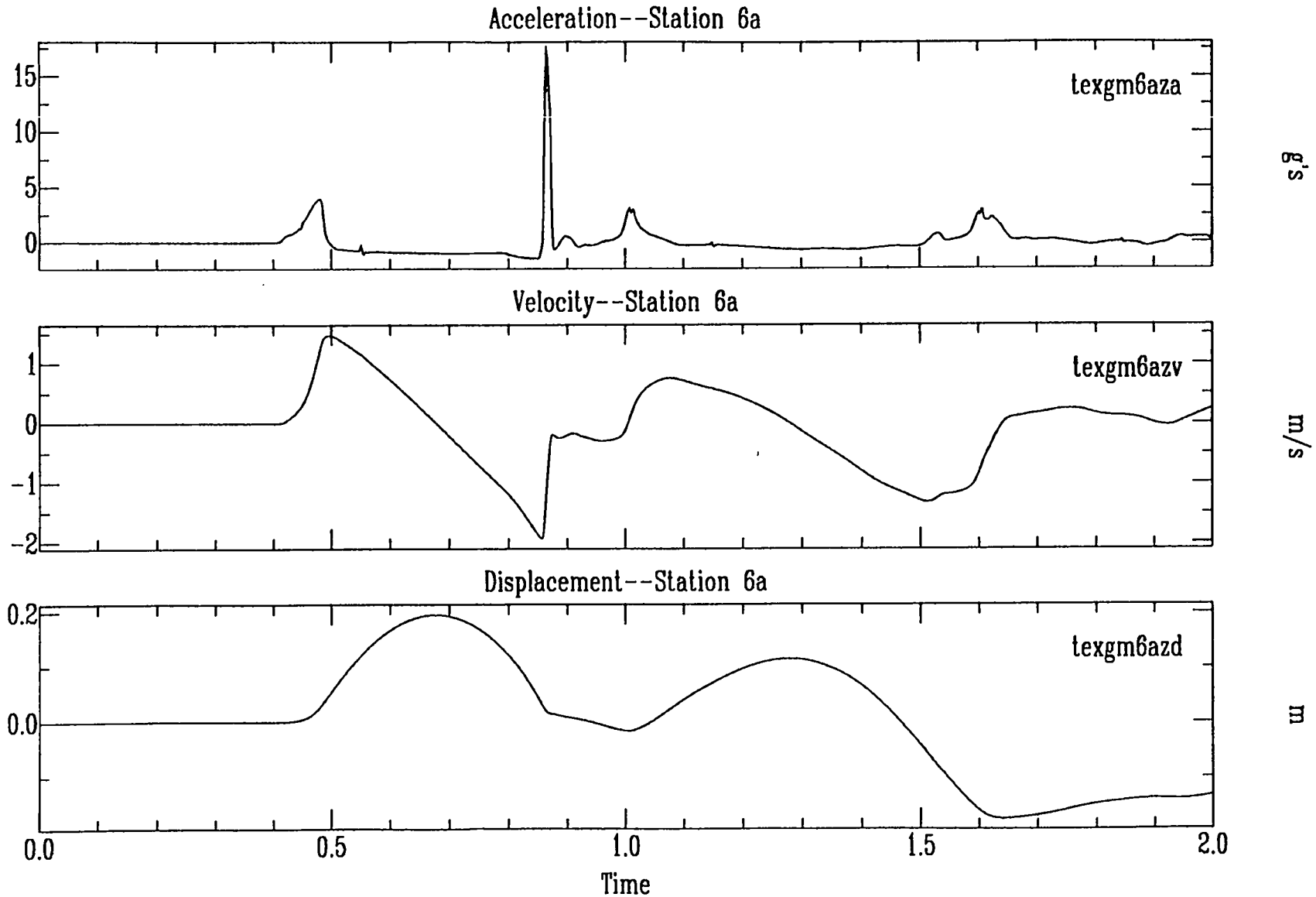

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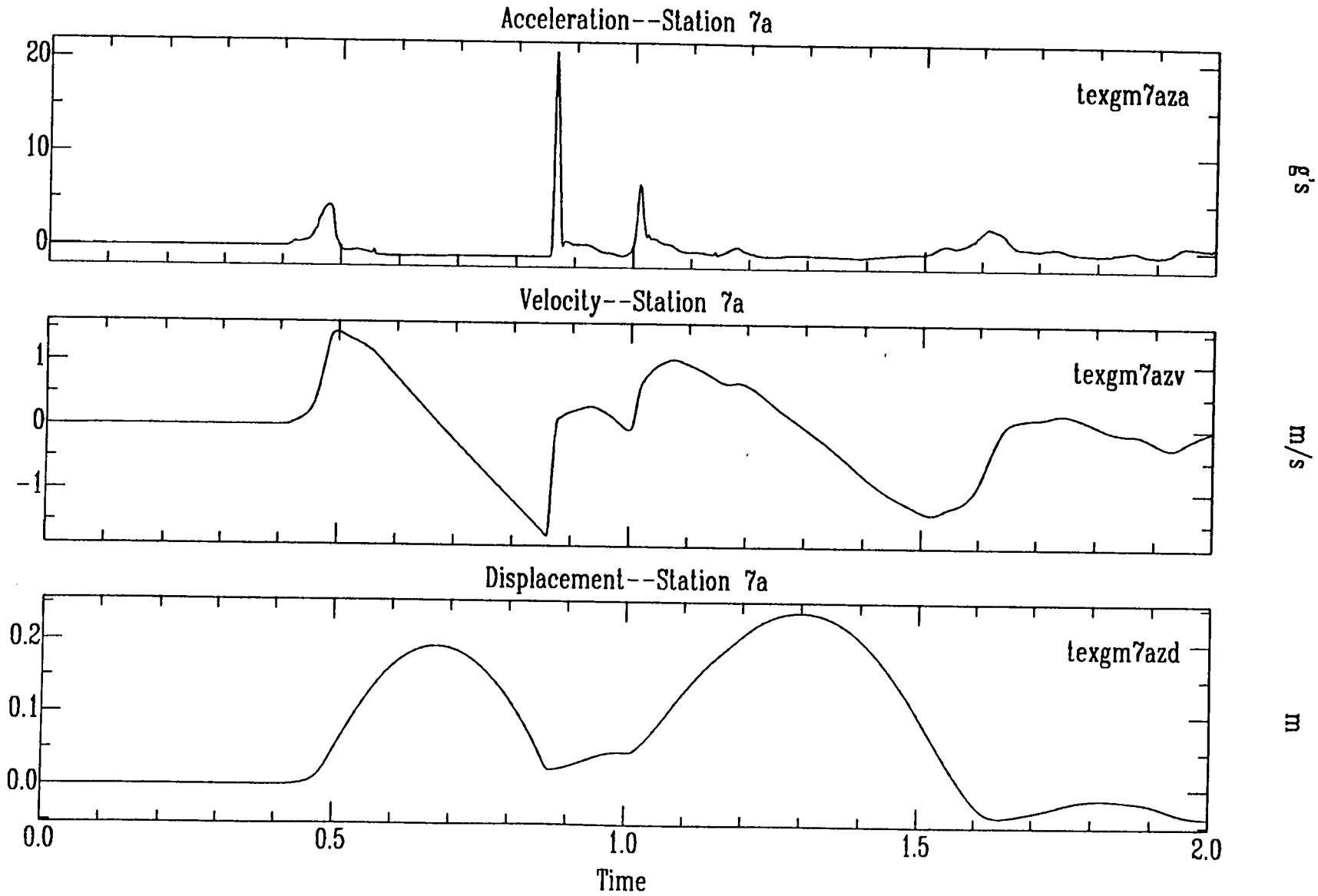

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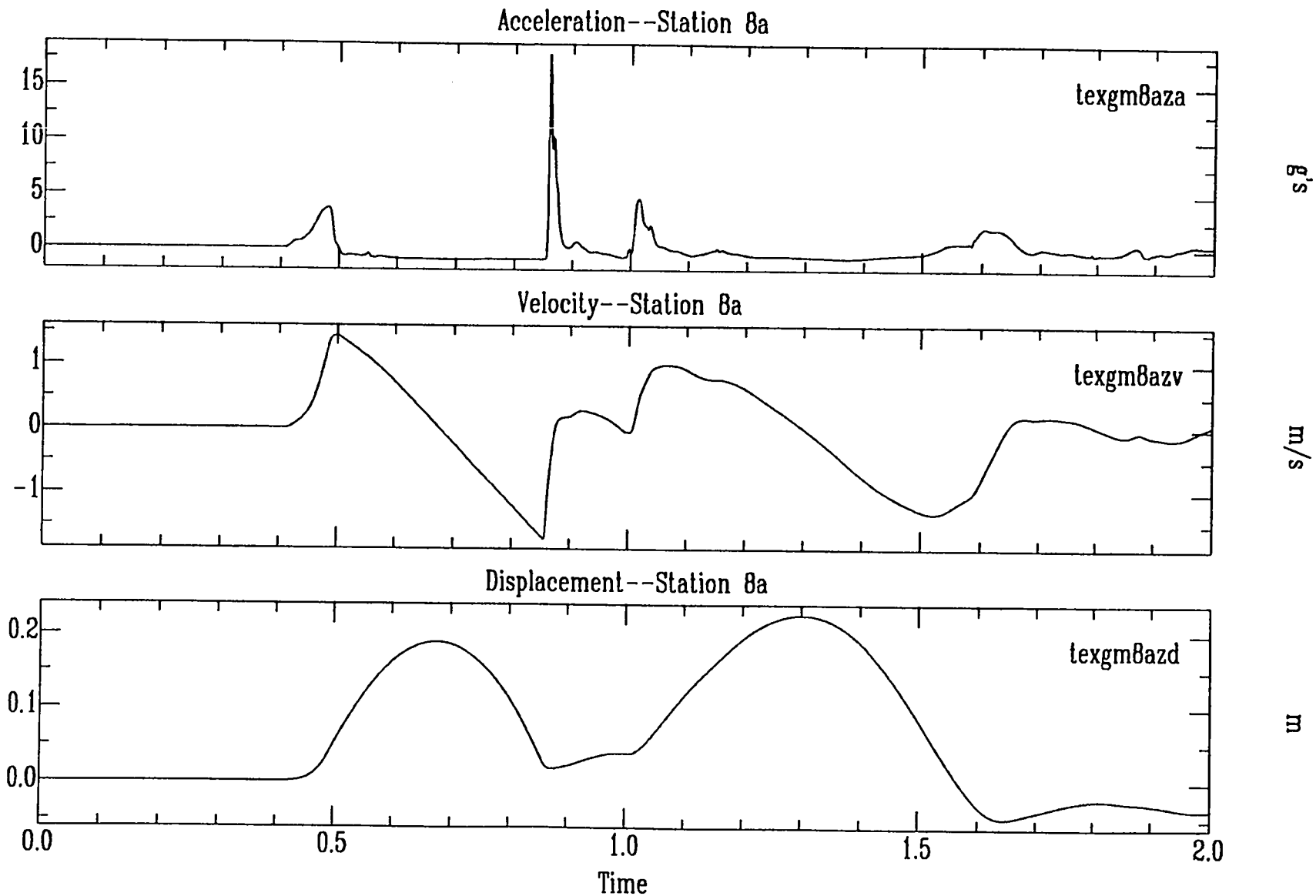

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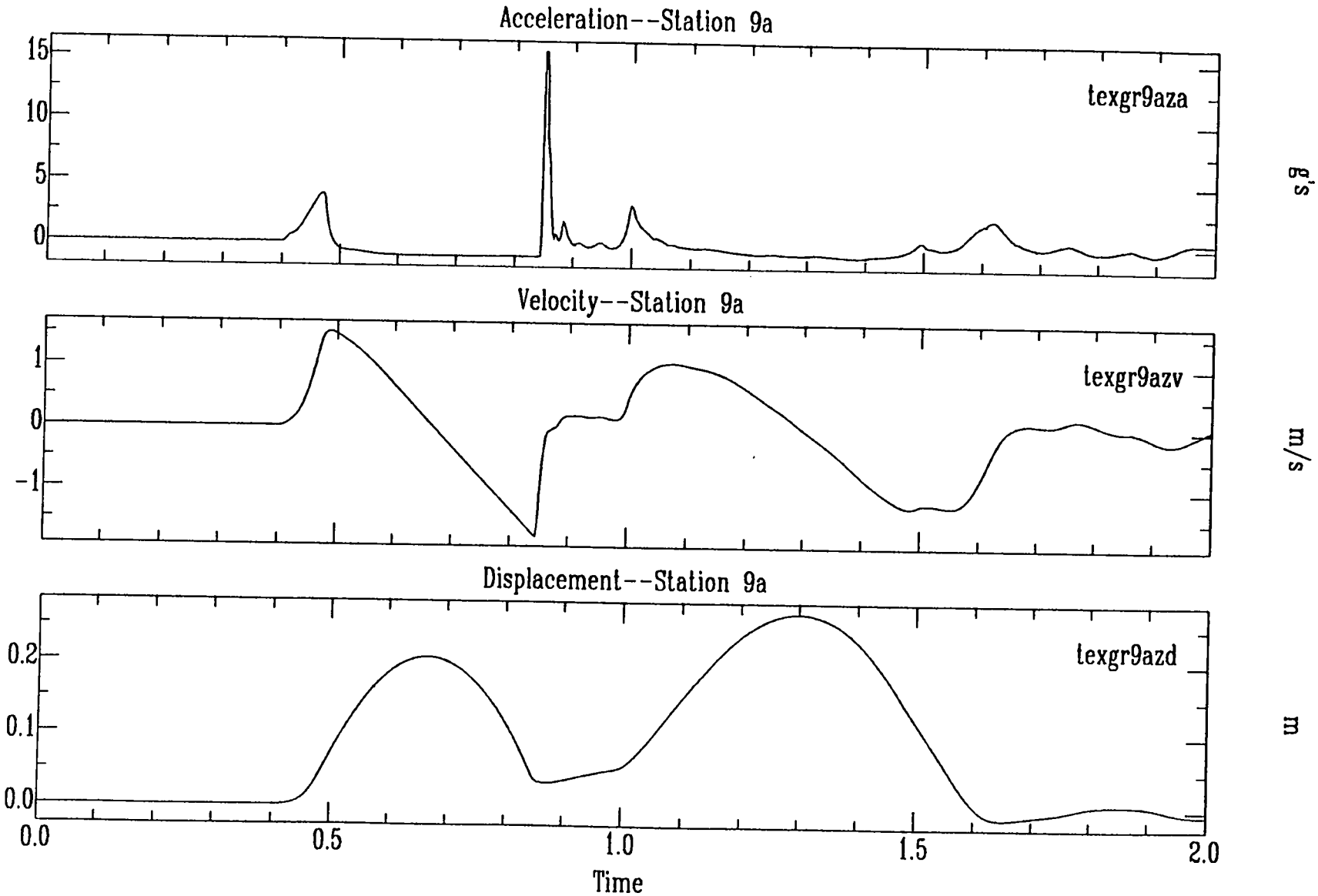
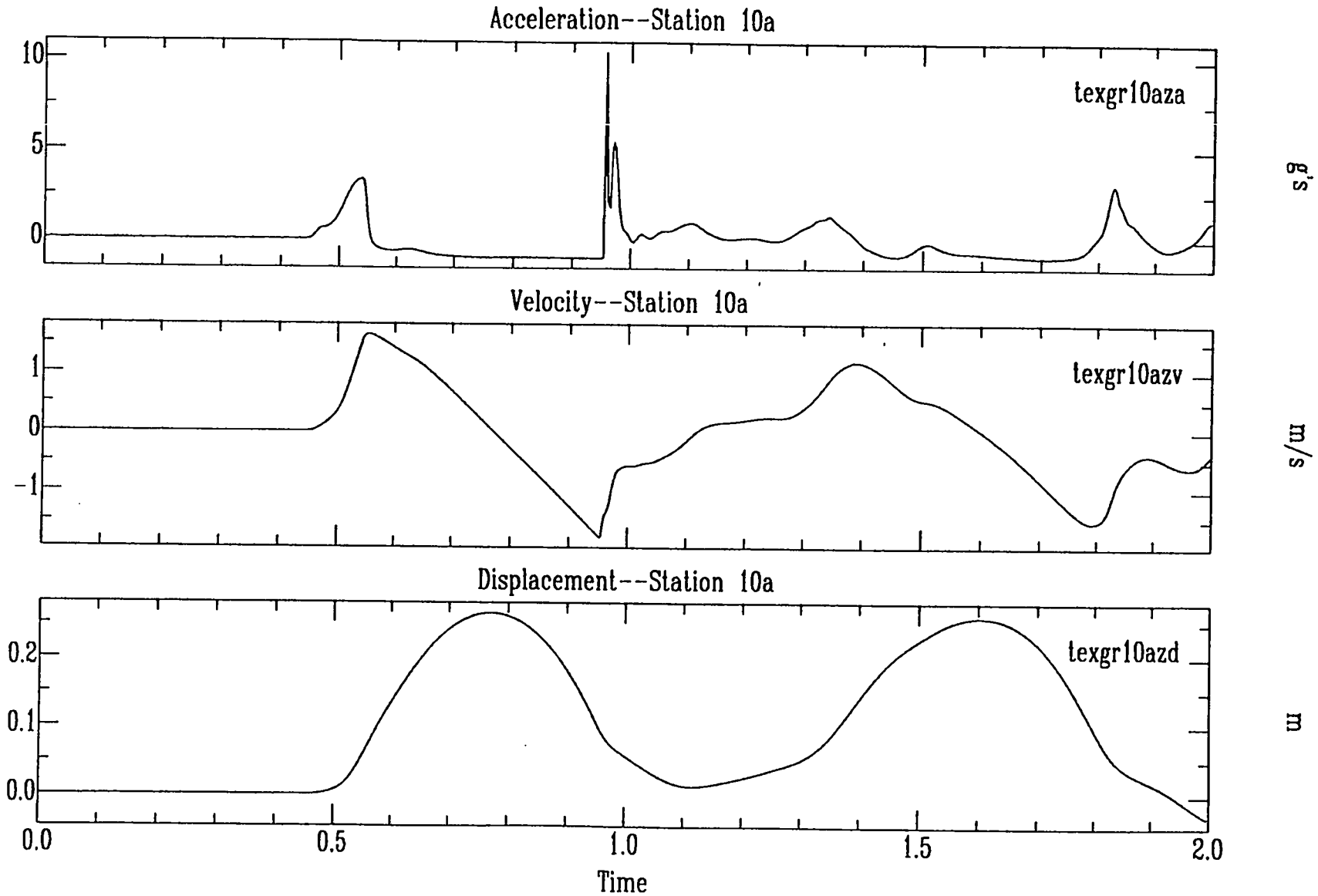


Texarkana Surface Ground Motion



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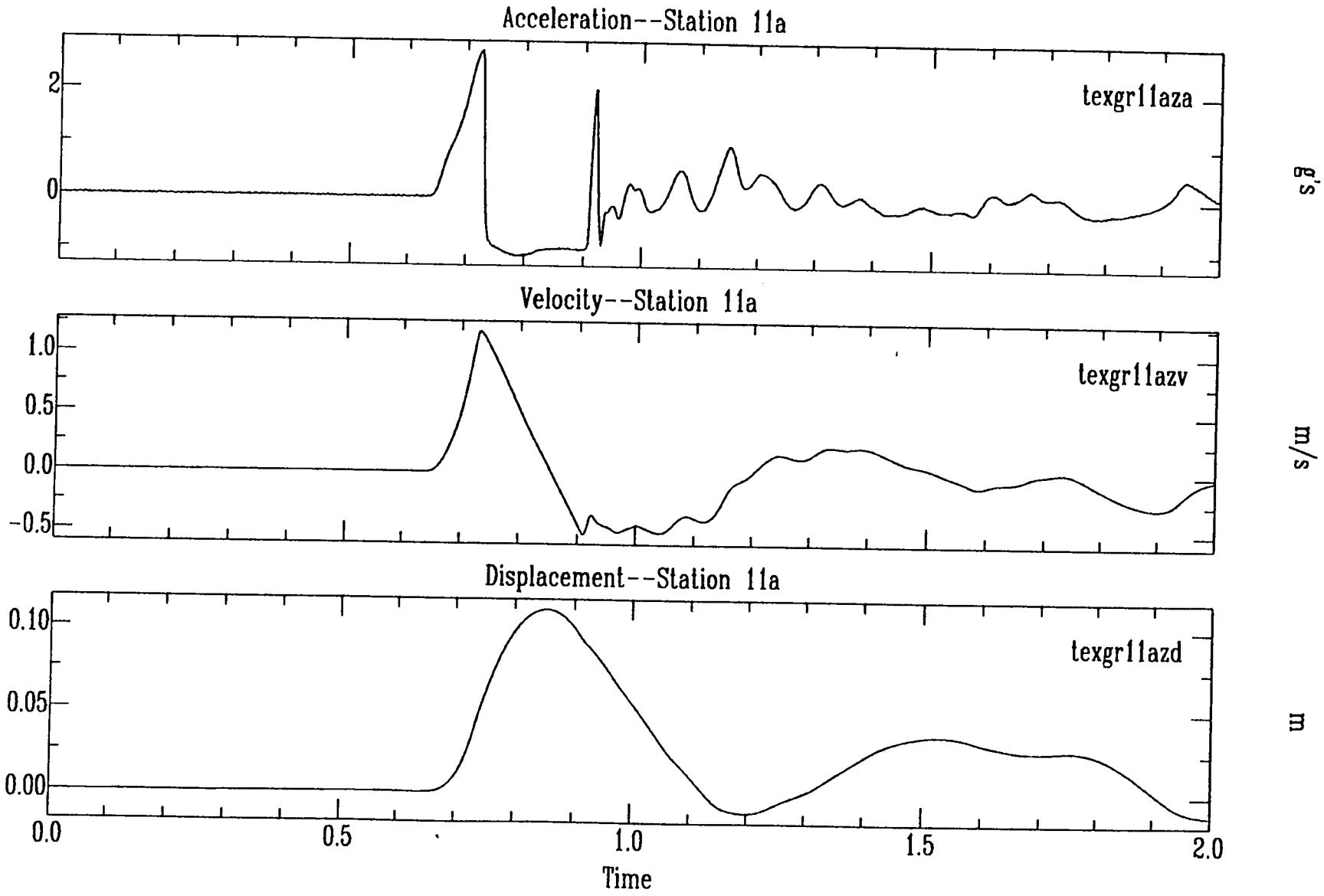
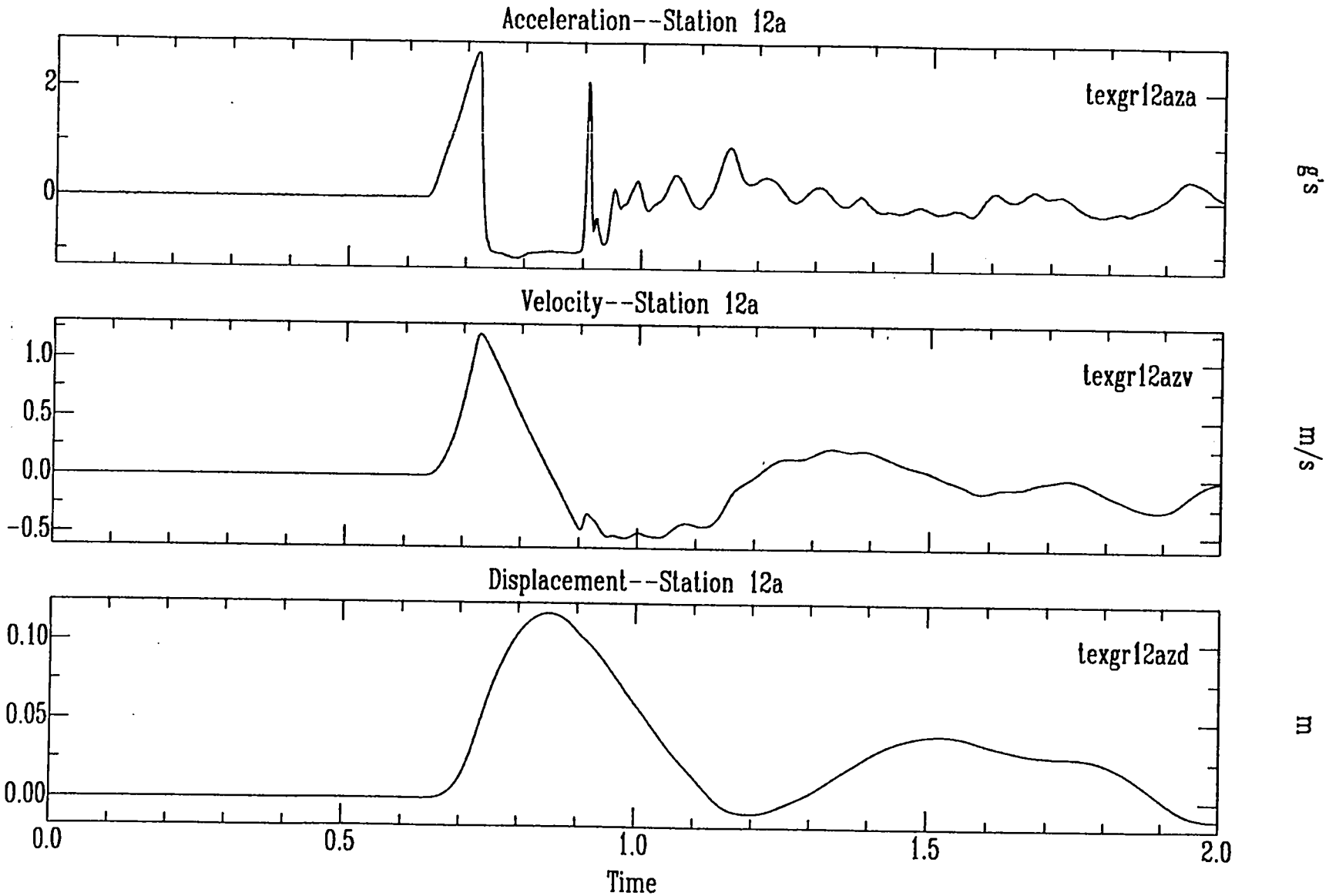


Texarkana Surface Ground Motion



4.3. Tulia (U4s)

Experiment design. The only ground-motion measurements on Tulia were from the nine-station J-8 accelerometer array for containment, including the three stations near SGZ (Fig. 5 and Table 3).

Results. The J-8 data were originally reported out in June 1989 (Memo J-8-89-142, R. S. Fitzhugh to F. N. App). All stations functioned properly, and spall was recorded on stations 1A, B and C, and 2A and B. All other stations recorded signals that did not contain spall characteristics. Figure 6 (9 pages) contains the station data traces for the accelerometer data.

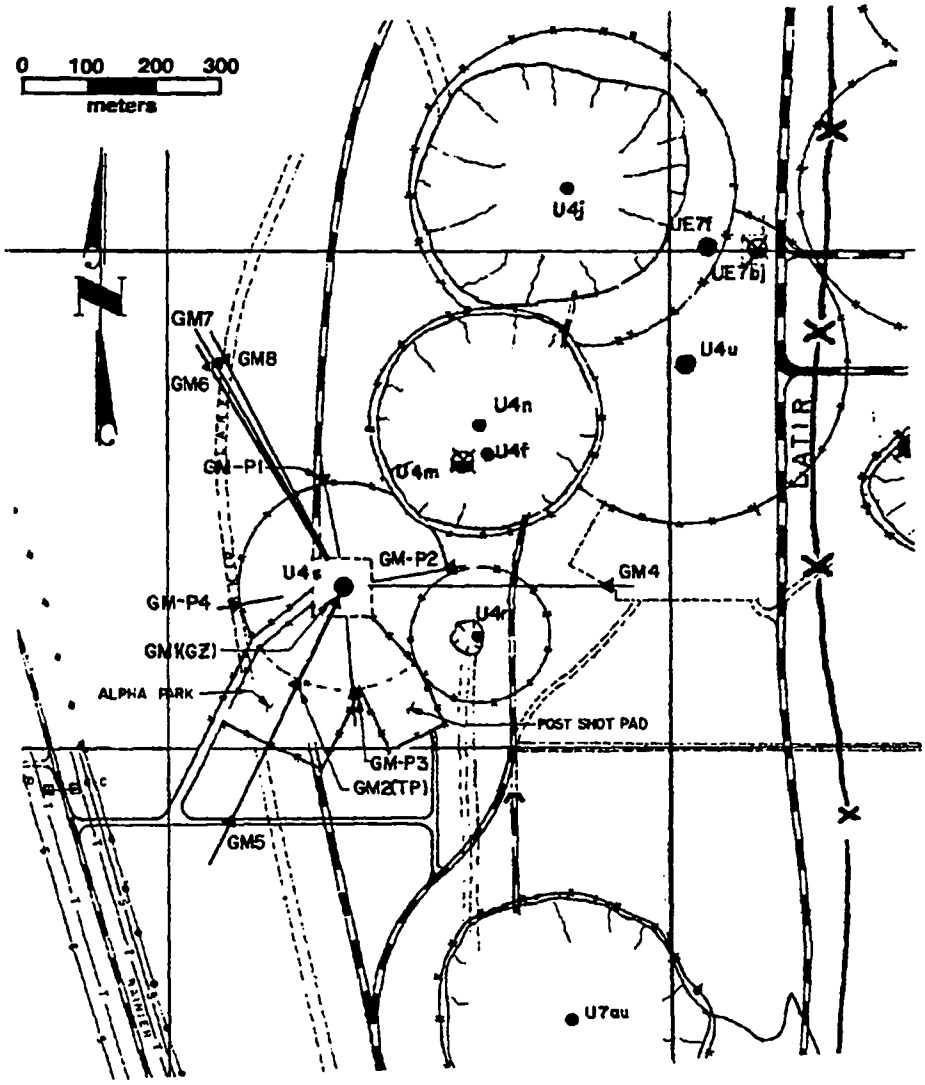
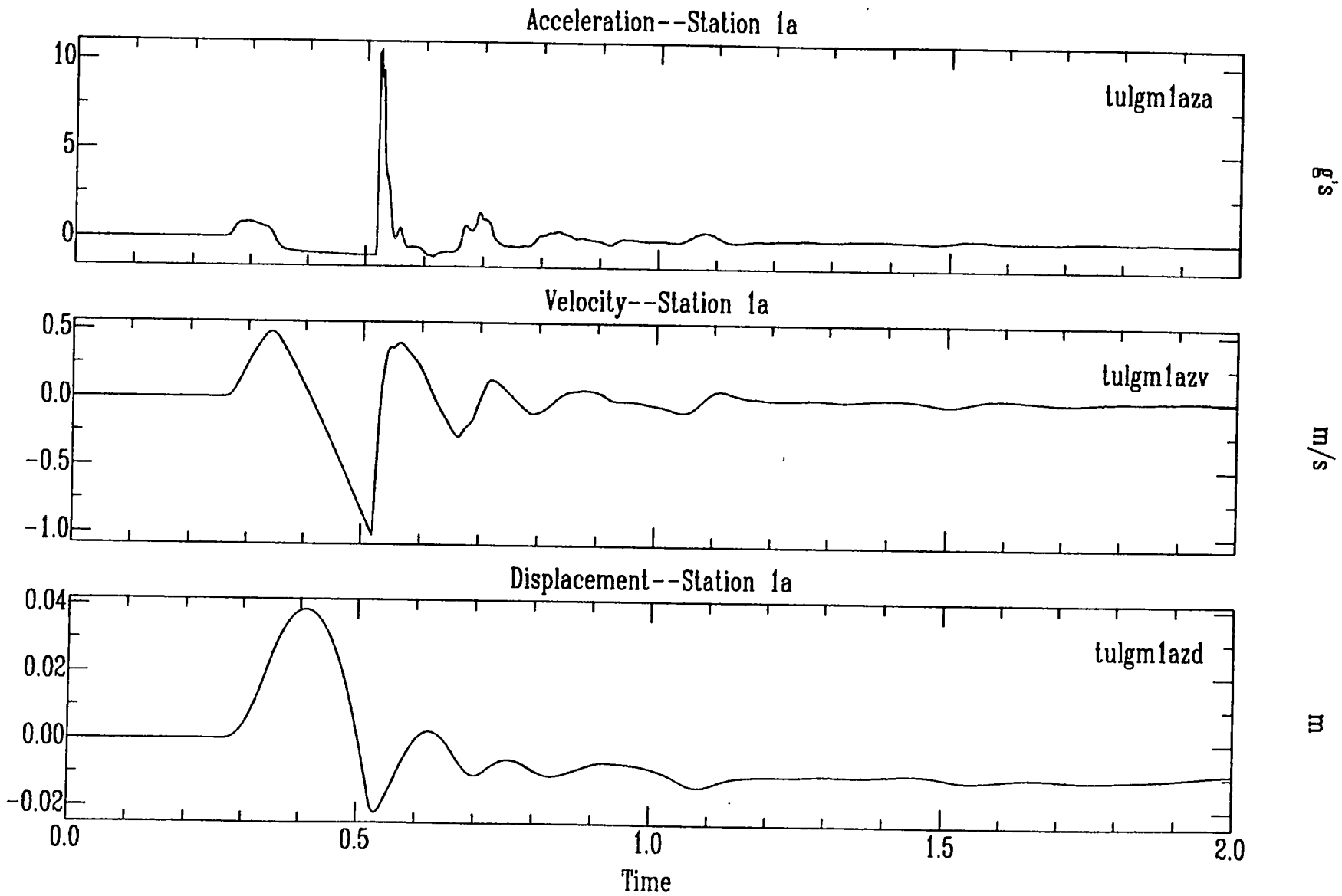


Fig. 5. Ground-motion-measurement array for Tulia.

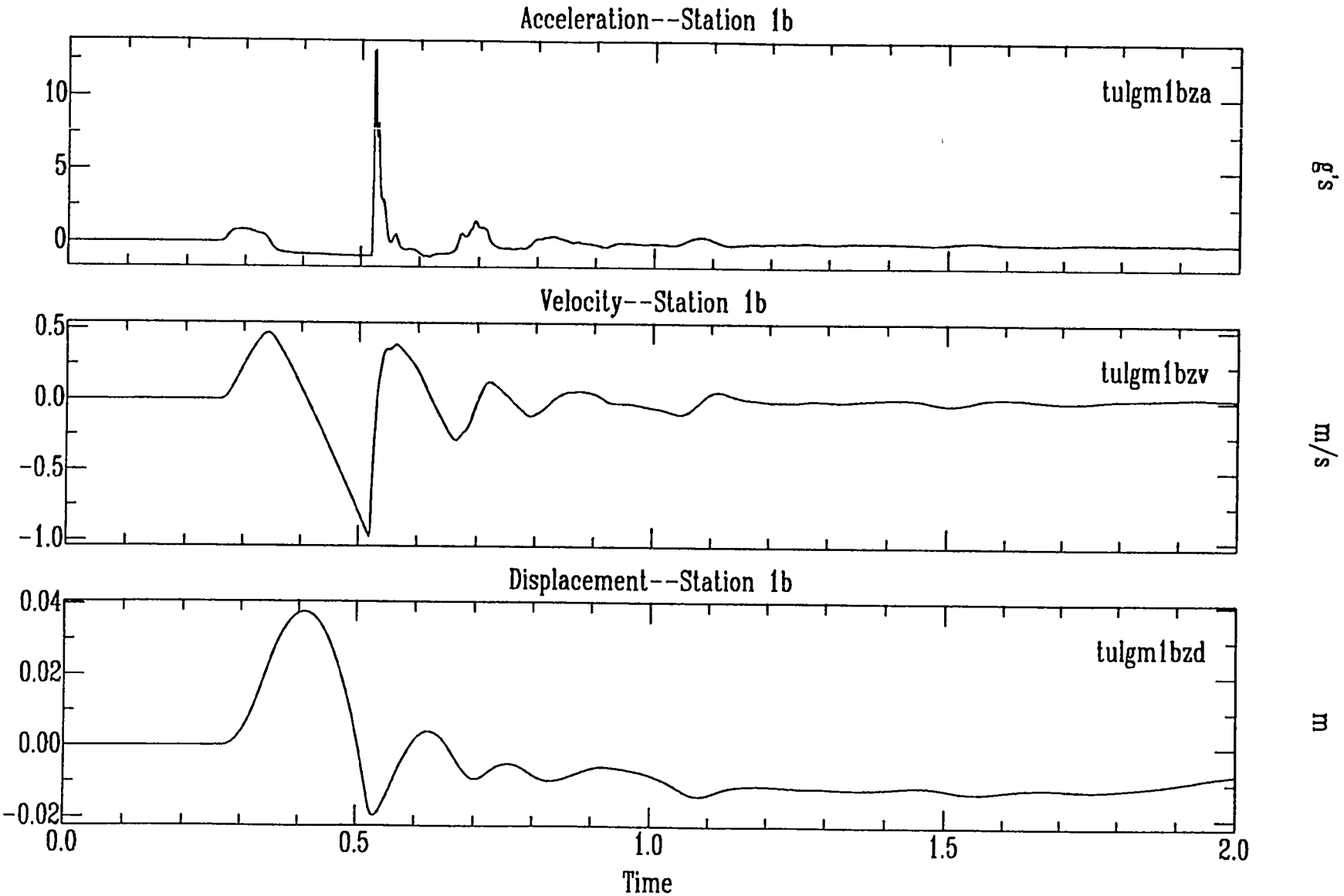
Table 3. Tulla Ground-Motion Station Data

Station Name	Station Loc U4s	Accelerometer	Northing (m) 259324	Easting (m) 206769	Slant Range 396 (m) DOB	TOA
TULGM1A	15 m S22W	Endevco 10 g	259310	206763	396	0.258
TULGM1B	15 m S22W	Endevco 25 g	259310	206763	396	0.259
TULGM1C	15 m S22W	Endevco 25 g	259310	206763	396	0.258
TULGM2A	160 m S23W	Endevco 25 g	259177	206707	427	0.28
TULGM2B	160 m S23W	Endevco 25 g	259177	206707	427	0.28
TULGM4A	396 m E	Endevco 10 g	259324	207165	560	0.365
TULGM5A	396 m S23W	Endevco 10 g	258959	206615	560	0.353
TULGM6A	396 m N30W	Endevco 10 g	259667	206571	560	0.365
TULGM7A	396 m N30W	Endevco 10 g	259669	206574	560	

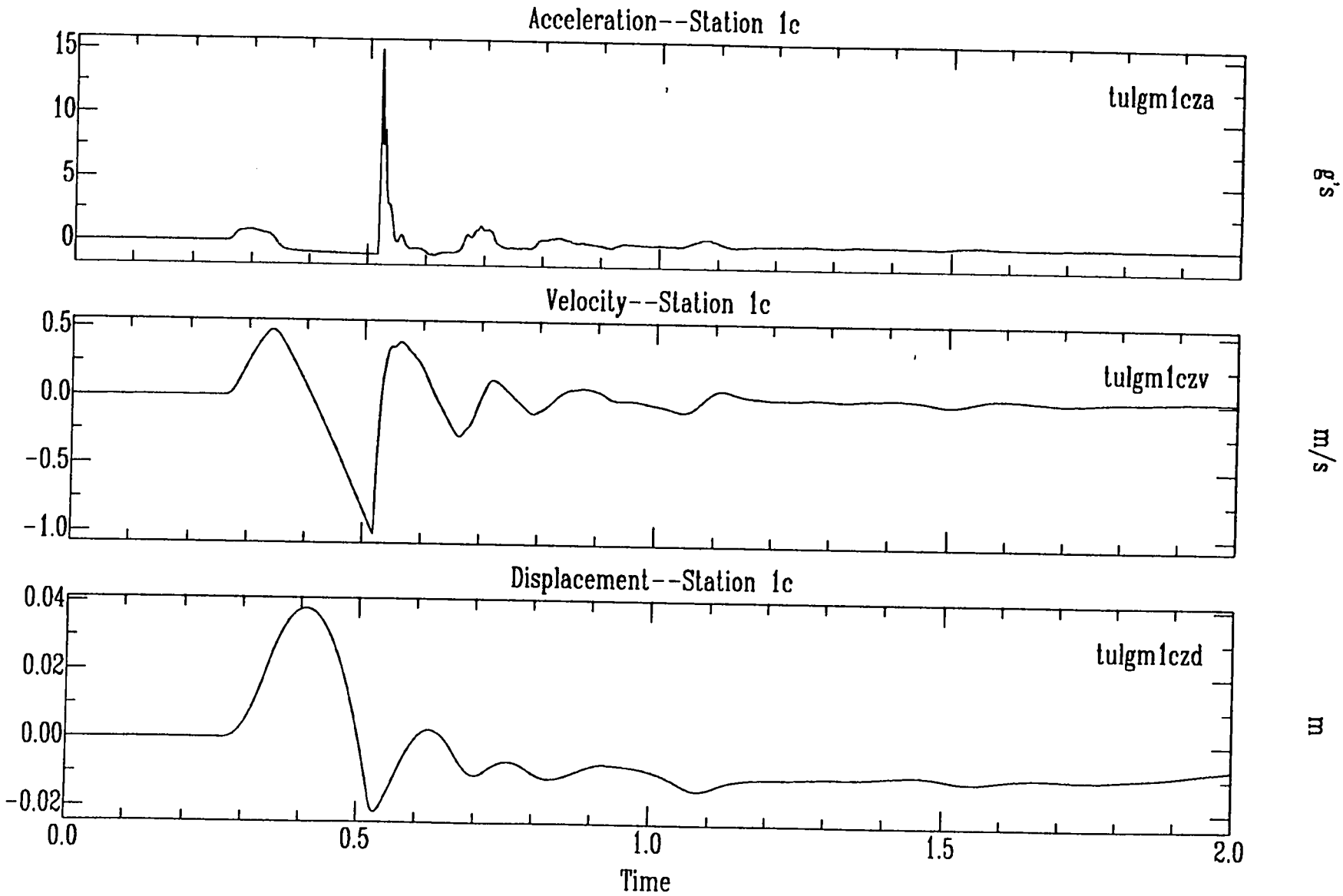
Tulia Surface Ground Motion



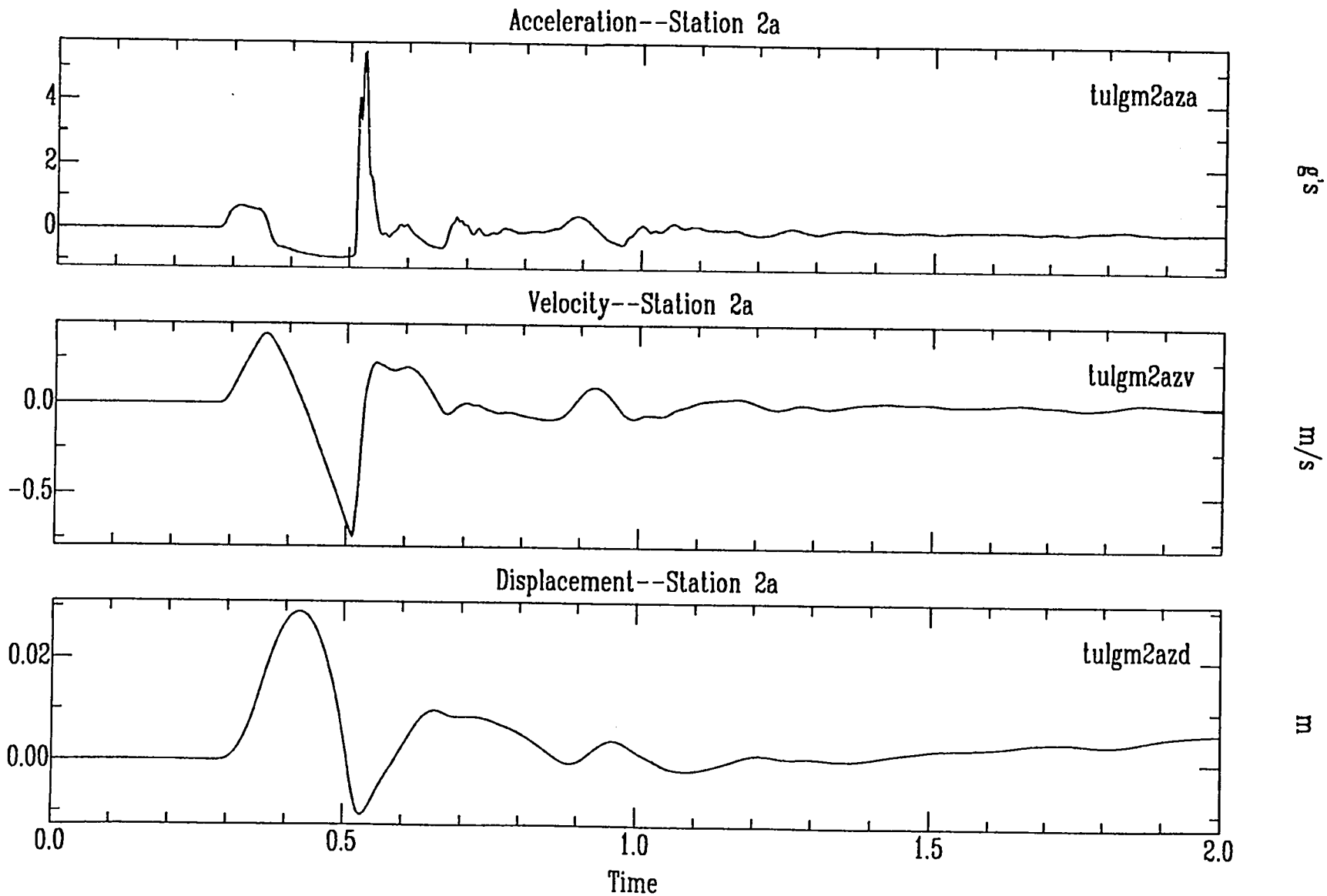
Tulia Surface Ground Motion



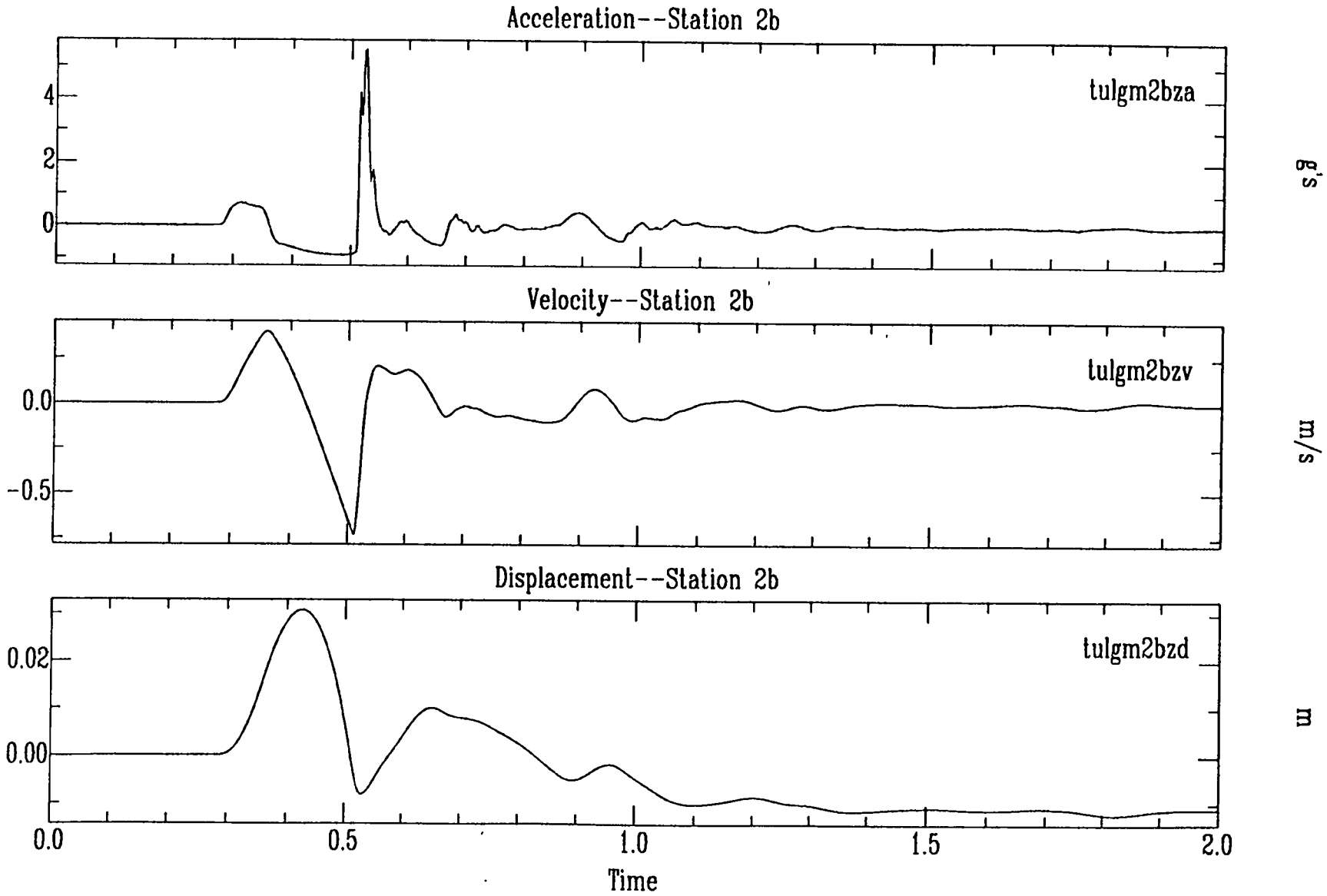
Tulia Surface Ground Motion



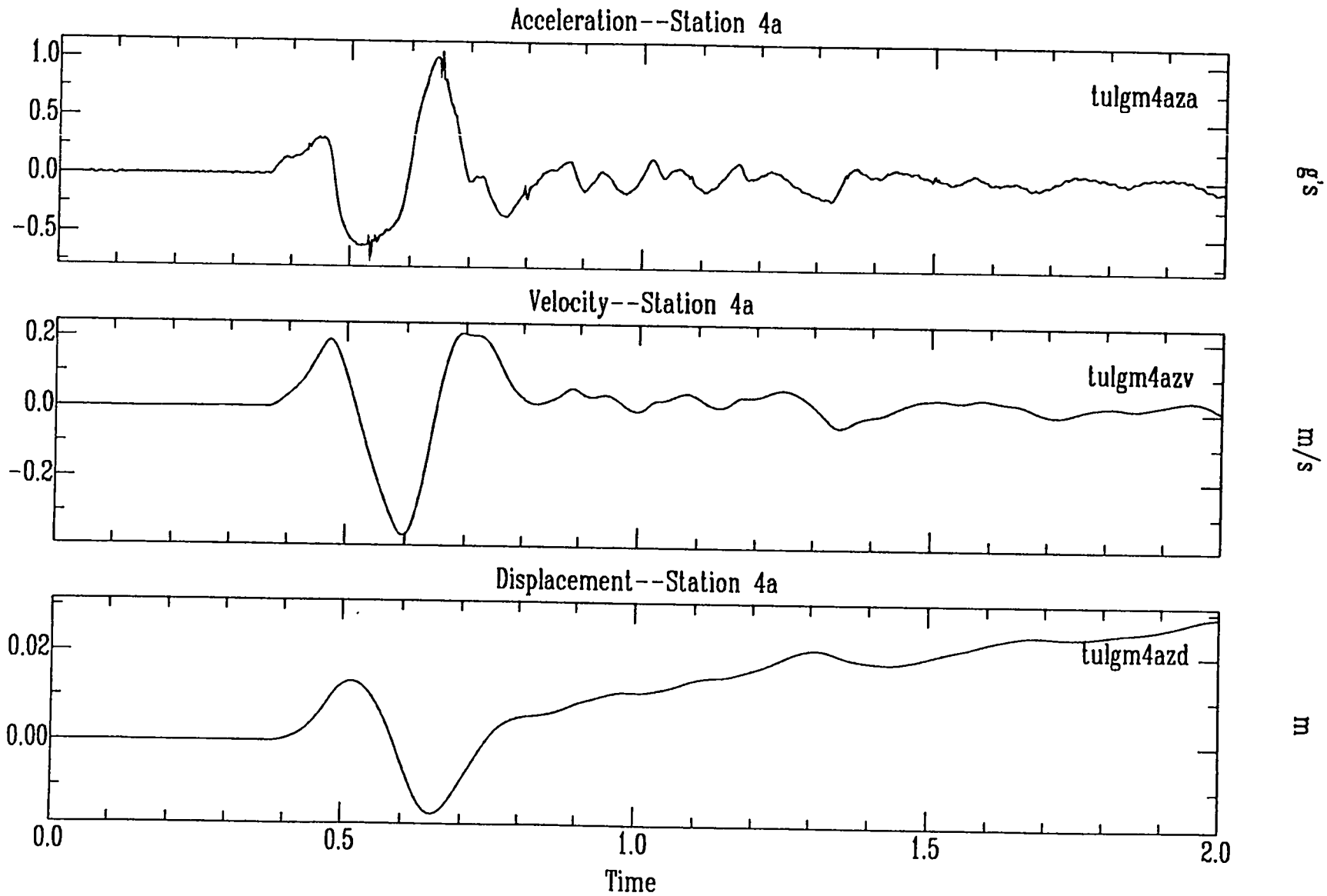
Tulia Surface Ground Motion



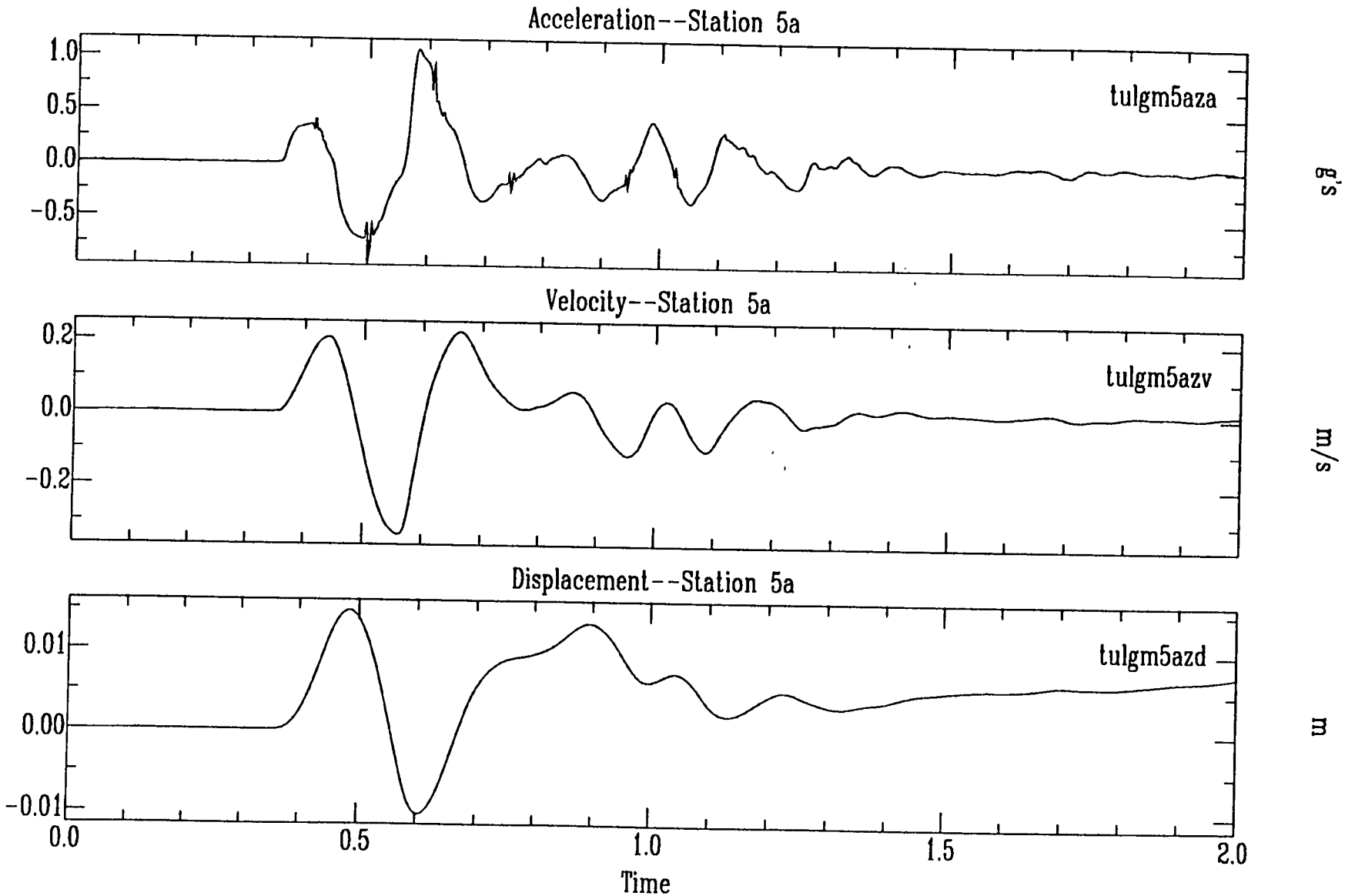
Tulia Surface Ground Motion



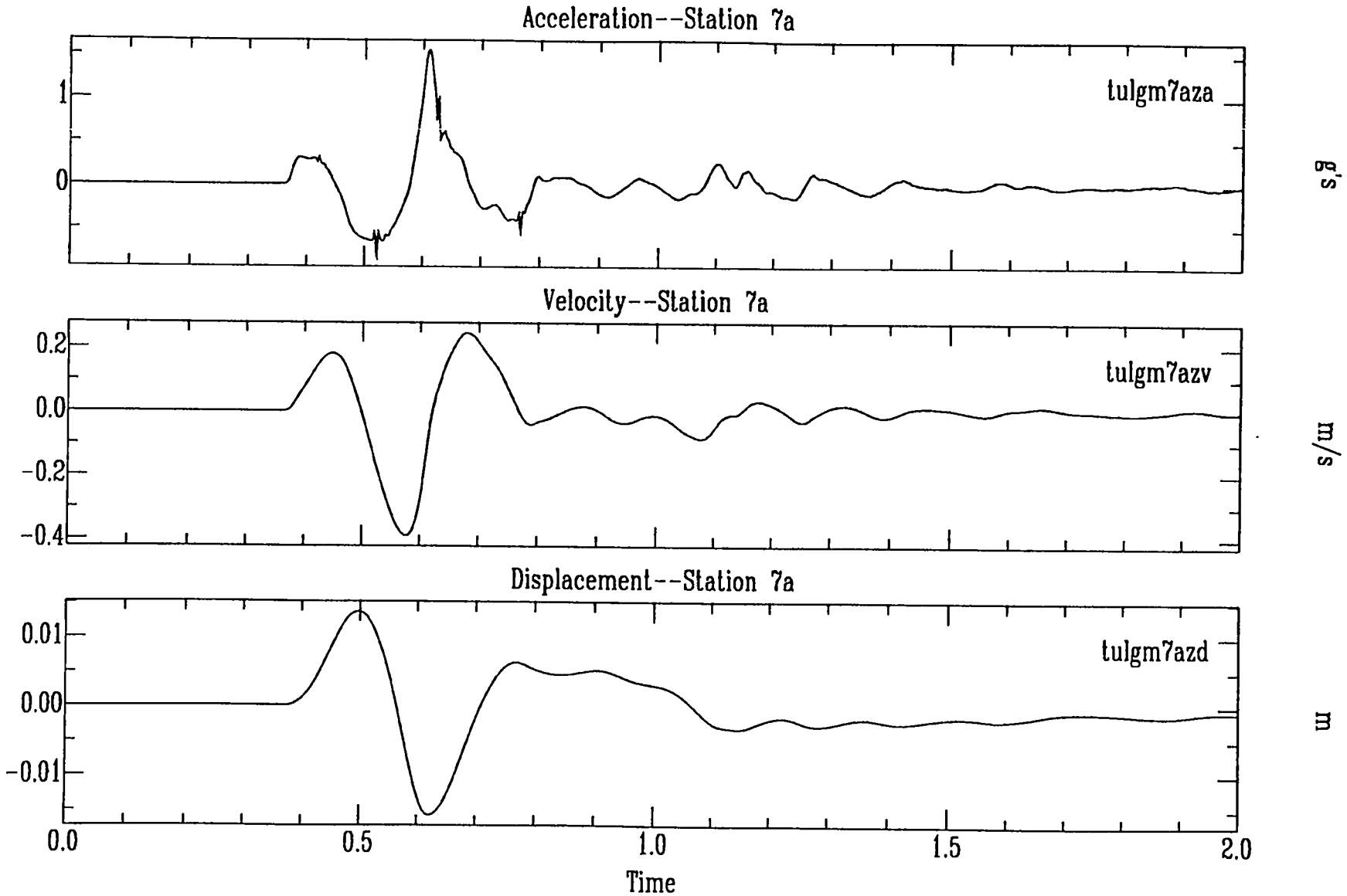
Tulia Surface Ground Motion



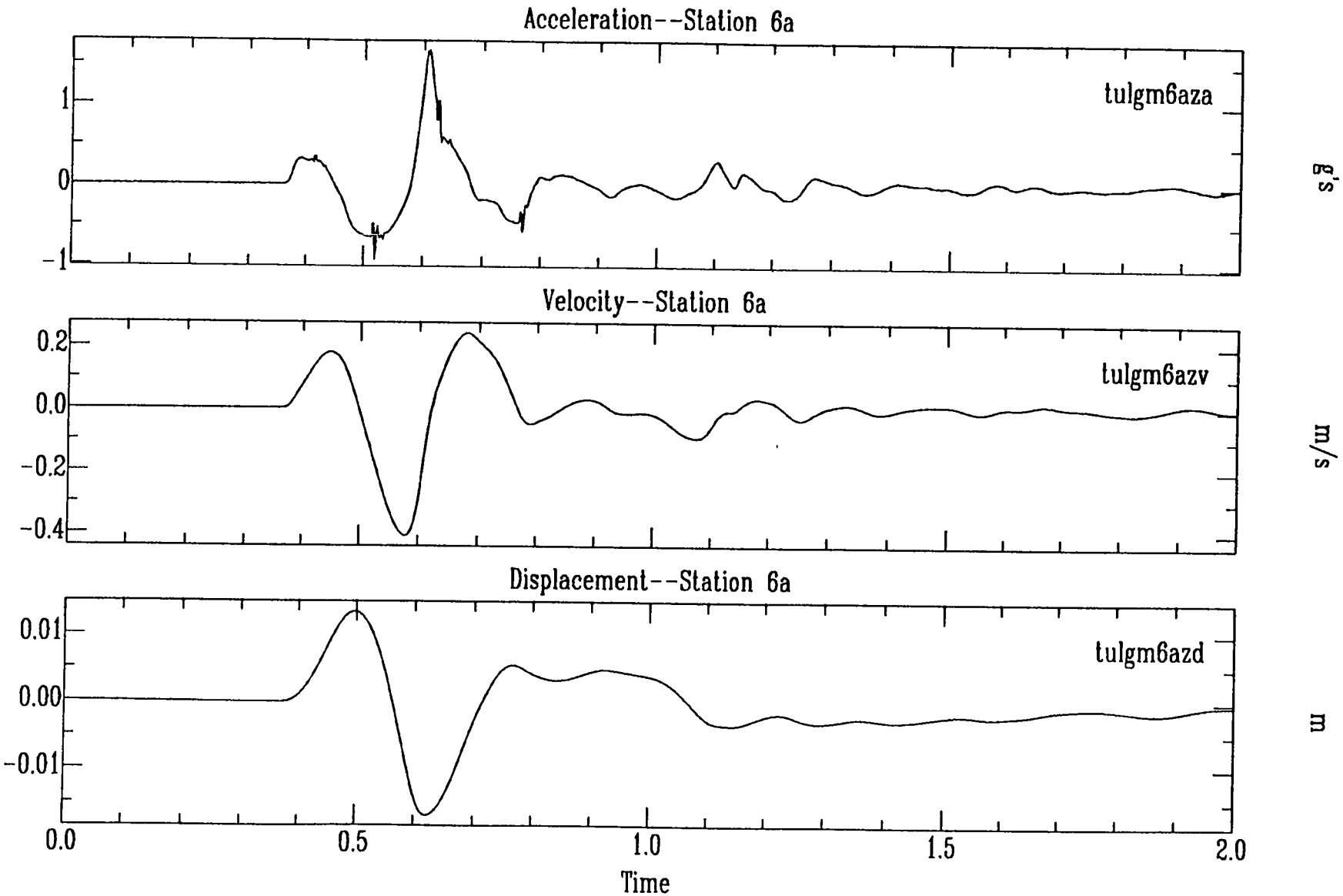
Tulia Surface Ground Motion



Tulia Surface Ground Motion



Tulia Surface Ground Motion



4.4. Contact (U20aw)

Experiment design. The only ground-motion measurement for Contact was the SIG experiment. Eleven arrays of golf balls (150 golf balls total) were installed around both the Contact and Amarillo emplacements. Table 4 is summary data about the arrays: number of balls, the approximate distance from the center of the array to Contact SGZ, and how each array was configured. The same configuration was used for both events (Fig. 7). Installation consisted of placing a golf ball directly on the ground (no dish), or into a plastic dish (15.4-cm diameter and 4-cm lip) that was partially filled with soil and placed onto the ground surface.

Eight of the arrays (four around each emplacement) were placed across a 600-m zone that spanned the predicted edges of spall. The other three arrays were placed approximately halfway between the two events.

Table 4. SIG Arrays for Contact
(see also Fig. 7)

Array	Ball Total	Ball Nos.	Dist.(m)	Configuration
1	15	1-15	3050	3x5 rectangular array, about 50-m spacing between balls
2	15	16-30	2600	3x5 rectangular array, about 50-m spacing between balls
3	14	31-44	1680	2 parallel lines, balls 100-m spacing, lines 20-m spacing
4	10	45-54	1525	2 parallel lines, balls 100-m spacing, lines 20-m spacing
5	8	55-62	1525	2 parallel lines, balls 100-m spacing, lines 20-m spacing
6	10	63-72	1525	2 parallel lines, balls 100-m spacing, lines 20-m spacing
7	24	73-96	3660	4x6 rectangular array, 50-m spacing
8	8	97-104	5200	1 line, 50-m spacing
9	10	105-114	7000	2 parallel lines, balls 100-m spacing, lines 20-m spacing
10	10	115-124	6700	2 parallel lines, balls 50-m spacing, lines 10-m spacing
11	26	125-150	6550	1 line, 2 balls at each location, 50-m spacing

SIG results. Results of the SIG experiment can be found in Table 5. Three of the golf balls moved a significant distance: (1) Golf ball 22 (GB22), located in the east-central part of Array 2, jumped 6.4 m at 95° azimuth; (2) GB32 jumped almost 3 m at 10°, and the dish it was in moved about 0.3 m; and (3) GB41, located 10 m N of GB32, moved about 8.8 m at 40°. Both GB32 and GB41 were located about 50 m east of the U20au pad. All three of these balls appear to have been placed in close proximity to fault systems.

The rest of the balls moved very little. Six other balls moved more than 10 cm. None of the balls that moved showed any indication of more than one direction of movement, i.e., rolling backward and forward.

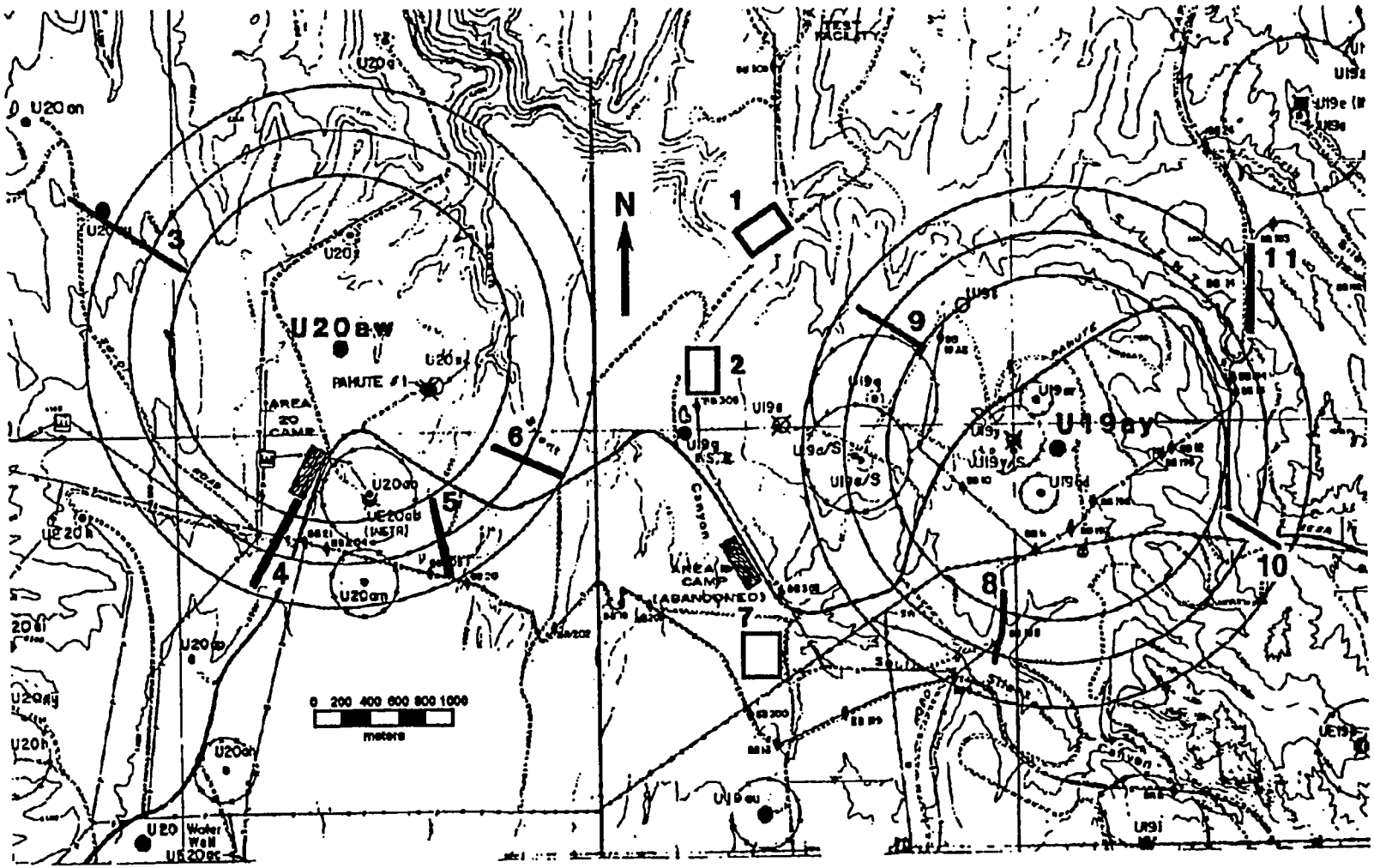


Fig. 7. Contact/Amarillo experiment map.

Table 5. Contact SIG Results

Ball	Array	Movement Dist (cm)	Az	Placement	Comments
1	1	0	0	ground	
2	1	0	0	ground	
3	1	0	0	ground	
4	1	0	0	ground	
5	1	0	0	ground	
6	1	2.5	255	ground	
7	1	0	0	ground	
8	1	0	0	ground	
9	1	0	0	ground	
10	1	0	0	ground	
11	1	8.9	70	ground	Downslope
12	1	0	0	ground	
13	1	0	0	ground	
14	1	0	0	ground	
15	1	5.1	310	ground	Crack through clearing
16	2	7.6	15	ground	Downslope
17	2	10.2	340	ground	
18	2	19.1	240	ground	Downslope
19	2	0	0	ground	
20	2	10.2	255	ground	
21	2	0	0	ground	
22	2	640.1	95	ground	
23	2	0	0	ground	Rolled but stopped at origin
24	2	0	0	ground	
25	2	0	0	ground	
26	2	2.5	285	ground	
27	2	10.2	345	ground	
28	2	34.3	315	ground	Downslope
29	2	0	0	ground	
30	2	0	0	ground	
31	3	0	0	dish	
32	3	289.6	20	dish	Pan moved ≈30.5 cm north
33	3	0	0	dish	
34	3	0	0	dish	
35	3	0	0	dish	
36	3	0	0	dish	
37	3	0	0	dish	
38	3	0	0	dish	
39	3	0	0	dish	
40	3	0	0	dish	
41	3	887.7	55	dish	
42	3	0	0	dish	
43	3	0	0	dish	
44	3	0	0	dish	
45	4	0	0	dish	

Table 5. Contact SIG Results (Continued)

Ball	Array	Movement Dist (cm)	Az	Placement	Comments
46	4	7.6	45	dish	
47	4	7.6	135	dish	
48	4	7.6	235	dish	
49	4	0	0	dish	
50	4	0	0	dish	
51	4	2.5	15	dish	Deer track next to dish
52	4	0	0	dish	
53	4	7.6	75	dish	E-W hairline crack next to dish
54	4	0	0	dish	
55	5	0	0	dish	
56	5	7.6	250	dish	Dish slid 13-15 cm
57	5	0	0	dish	
58	5	7.6	225	dish	
59	5	0	0	dish	
60	5	0	0	dish	
61	5	0	0	dish	
62	5	0	0	dish	
63	6	0	0	dish	
64	6	0	0	dish	
65	6	7.6	105	dish	Downslope
66	6	0	0	dish	
67	6	0	0	dish	
68	6	0	0	dish	Gully bottom
69	6	5.1	60	dish	
70	6	3.8	60	dish	
71	6	7.6	75	dish	
72	6	7.6	60	dish	
73	7	0	0	dish	
74	7	0	0	dish	
75	7	0	0	dish	
76	7	0	0	dish	
77	7	0	0	dish	
78	7	2.5		dish	Rolled into a depression
79	7	2.5	195	dish	
80	7	2.5	195	dish	
81	7	0	0	dish	
82	7	2.5	15	dish	
83	7	2.5	105	dish	
84	7	2.5	195	dish	
85	7	2.5	150	dish	
86	7	2.5	195	dish	
87	7	0	0	dish	
88	7	0	0	dish	
89	7	0	0	dish	

Table 5. Contact SIG Results (Continued)

Ball	Array	Movement Dist (cm)	Az	Placement	Comments
90	7	2.5	195	dish	Animal tracks near dish
91	7	0	0	dish	
92	7	0	0	dish	
93	7	2.5	195	dish	
94	7	0	0	dish	
95	7	2.5	340	dish	
96	7	15.2	150	dish	Animal tracks near dish
97	8	0	0	dish	
98	8	0	0	dish	
99	8	0	0	dish	
100	8	0	0	dish	
101	8	0	0	dish	
102	8	0	0	dish	
103	8	0	0	dish	
104	8	2.5	285	dish	
105	9	0	0	dish	
106	9	0	0	dish	
107	9	0	0	dish	
108	9	7.6	285	dish	
109	9	0	0	dish	
110	9	0	0	dish	
111	9	0	0	dish	
112	9	0	0	dish	
113	9	0	0	dish	
114	9	0	0	dish	
115	10	0	0	dish	
116	10	0	0	dish	
117	10	0	0	dish	
118	10	0	0	dish	
119	10	0	0	dish	
120	10	0	0	dish	
121	10	0	0	dish	
122	10	0	0	dish	
123	10	0	0	dish	
124	10	0	0	dish	
125	11	0	0	dish	North of Silent Canyon
126	11	0	0	dish	
127	1	0	0	dish	Same dish as Ball #150
128	11	0	0	dish	Same dish as Ball #149
129	11	0	0	dish	Same dish as Ball #148
130	11	0	0	dish	Same dish as Ball #147
131	11	0	0	dish	Same dish as Ball #146
132	11	0	0	dish	Same dish as Ball #145
133	11	0	0	dish	Dish adjacent to Ball #144
134	11	0	0	dish	Dish adjacent to Ball #143
135	11	0	0	dish	Dish adjacent to Ball #142

Table 5. Contact SIG Results (Concluded)

Ball	Array	Movement Dist (cm)	Az	Placement	Comments
136	11	0	0	dish	Dish adjacent to Ball #141
137	11	0	0	dish	Dish adjacent to Ball #140
138	11	0	0	dish	Dish adjacent to Ball #139
139	11	0	0	dish	Dish adjacent to Ball #140
140	11	0	0	dish	Dish adjacent to Ball #137
141	11	0	0	dish	Dish adjacent to Ball #136
142	11	0	0	dish	Dish adjacent to Ball #135
143	11	0	0	dish	Dish adjacent to Ball #134
144	11	0	0	dish	Dish adjacent to Ball #133
145	11	0	0	dish	Same dish as Ball #132
146	11	0	0	dish	Same dish as Ball #131
147	11	0	0	dish	Same dish as Ball #130
148	11	0	0	dish	Same dish as Ball #129
149	11	0	0	dish	Same dish as Ball #128
150	11	0	0	dish	Same dish as Ball #127

4.5. Amarillo (U19ay)

Experiment design. The identical SIG experiment conducted for Contact a week earlier was reset and repeated for Amarillo (see Fig. 7 and Table 6). Mapping and retrieval of the SIGs began within a few hours of event detonation. Amarillo also had a standard J-8 6-station accelerometer array (including 3 stations near SGZ) (see Fig. 8 and Table 7). All of these stations were within the predicted spall zone.

SIG results. Recovery of the SIGs and fracture mapping began within 4 hrs of event detonation. The weather prior to the event was hot and dry, with occasional wind gusts. This same weather pattern persisted for several days after the event. Postshot, very few of the SIGs had moved from their preshot positions (Table 7). Those few that did showed evidence of animal or bird tracks in the immediate vicinity or may have been moved as a result of the high wind gusts that were experienced the evening before the event (see comments in Table 7). There are no SIG movements that can uniquely be attributed to the ground motion from Amarillo.

Table 6. SIG Arrays for Amarillo
(see also Fig. 7)

Array	Ball Total	Ball Nos.	Dist.(m)	Configuration
1	15	1-15	2620	3x5 rectangular array, about 50-m spacing between balls
2	15	16-30	2620	3x5 rectangular array, about 50-m spacing between balls
3	14	31-44	6700	2 parallel lines, balls 100-m spacing, lines 20-m spacing
4	10	45-54	5790	2 parallel lines, balls 100-m spacing, lines 20-m spacing
5	8	55-62	4570	2 parallel lines, balls 100-m spacing, lines 20-m spacing
6	10	63-72	3960	2 parallel lines, balls 100-m spacing, lines 20-m spacing
7	24	73-96	2620	4x6 rectangular array, 50-m spacing
8	8	97-104	1340	1 line, 50-m spacing
9	10	105-114	1520	2 parallel lines, balls 100-m spacing, lines 20-m spacing
0	10	115-124	1520	2 parallel lines, balls 50-m spacing, lines 10-m spacing
11	26	125-150	1830	1 line, 2 balls at each location, 50-m spacing

Accelerometer results. The J-8 data were originally reported out in July 1989 (Memo J-8-89-165, R. S. Fitzhugh to F. N. App). All but one of the J-8 accelerometers (AMAGM6A) recorded spall signals. Station 6A looks similar to a spall record, but the first maximum acceleration was just less the 1-g upward, and the dwell between first peak and slapdown never exceeded -0.4 g, whereas -1.0 g would normally indicate spall. Figure 9 (continued over 8 pages) contains the data traces for the accelerometer data.

Table 7. Amarillo J-8 Ground-Motion Station Data

Station Name	Station Loc u19ay	Accelerometer	Northing (m) 280233	Easting (m) 180167	Slant Range 640 (m) DOB	Travel Time
AMAGM1A	15m N38E	Endevco 10 g	2802451	80177	640	0.32
AMAGM1B	15m N38E	Endevco 25 g	280245	180177	640	0.321
AMAGM1C	15m N38E	Endevco 25 g	280245	180177	640	0.32
AMAGM2A	258m N38E	Endevco 25 g	280436	180325	690	0.347
AMAGM2B	258m N38E	Endevco 25 g	280436	180325	690	0.347
AMAGM4A	640m N20E	Endevco 20 g	280834	180386	905	0.44
AMAGM5A	644m S39E	Endevco 20 g	279731	180570	908	0.418
AMAGM6A	640m S80W	Endevco 20 g	280122	179537	905	0.442

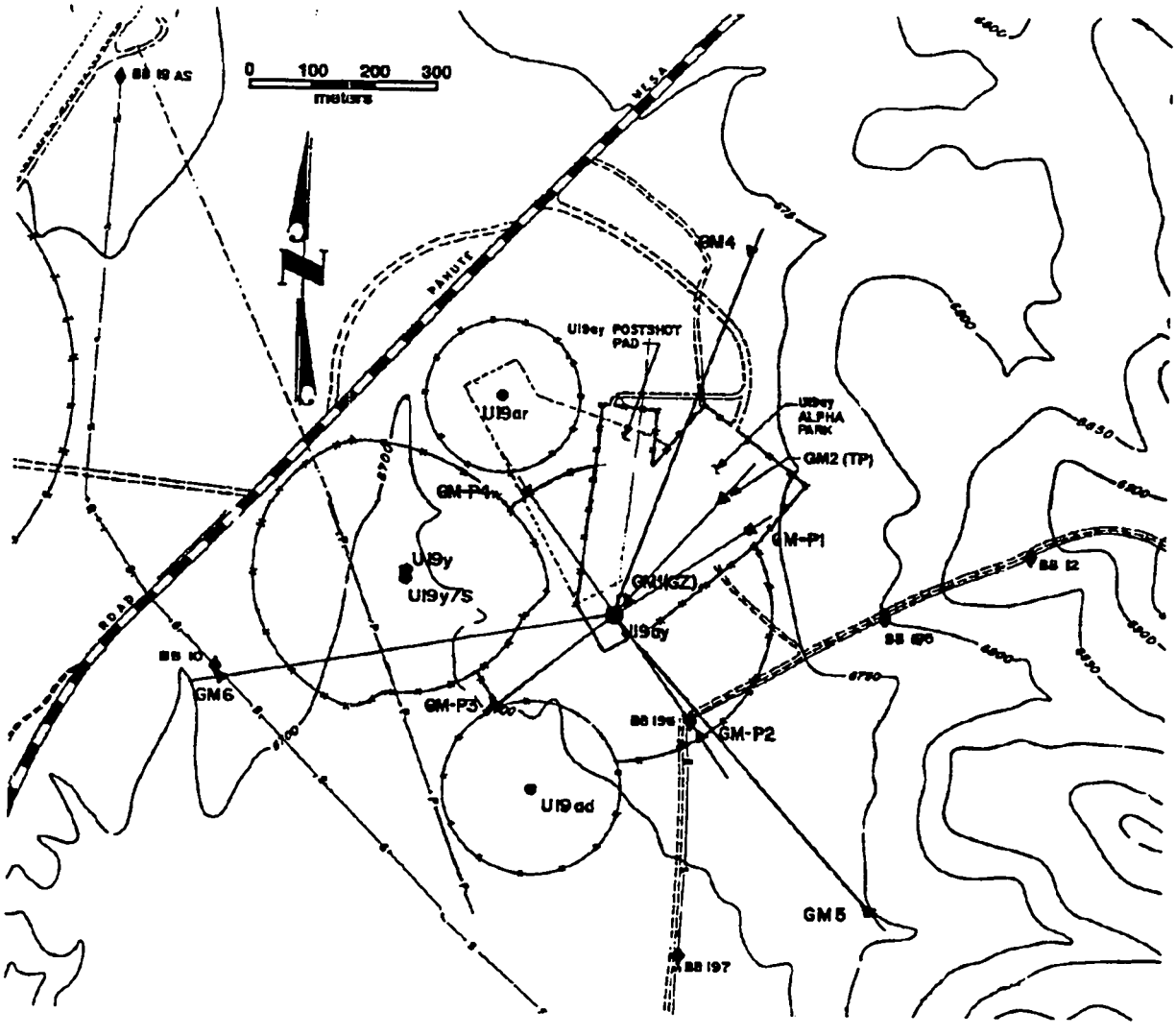


Fig. 8. Ground-motion stations for Amarillo.

Table 8. Amarillo SIG Results

Ball	Array	Movement Dist (cm)	Az	Placement	Comment
1	1	2.5	195	ground	Wind?
2	1	0	0	ground	
3	1	0	0	ground	
4	1	0	0	ground	
5	1	0	0	ground	
6	1	0	0	ground	
7	1	0	0	ground	
8	1	0	0	ground	
9	1	0	0	ground	
10	1	0	0	ground	
11	1	0	0	ground	
12	1	0	0	ground	
13	1	0	0	ground	
14	1	0	0	ground	
15	1	0	0	ground	
16	2	5.1	25	ground	
17	2	0	0	ground	
18	2	0	0	ground	
19	2	0	0	ground	
20	2	0	0	ground	
21	2	0	0	ground	
22	2	0	0	ground	
23	2	0	0	ground	
24	2	0	0	ground	
25	2	0	0	ground	
26	2	0	0	ground	
27	2	0	0	ground	
28	2	0	0	ground	
29	2	0	0	ground	
30	2	0	0	ground	
31	3	7.6	15	dish	Wind?
34	3	0	0	dish	
35	3	0	0	dish	
36	3	0	0	dish	
37	3	0	0	dish	
38	3	0	0	dish	
39	3	0	0	dish	
40	3	0	0	dish	
41	3	0	0	dish	
42	3	0	0	dish	
43	3	0	0	dish	
44	3	0	0	dish	
45	4	0	0	dish	
46	4	0	0	dish	
47	4	0	0	dish	

Table 8 Amarillo SIG Results (Continued)

Ball	Array	Movement Dist (cm)	Az	Placement	Comment
48	4	0	0	dish	
49	4	0	0	dish	
50	4	0	0	dish	
51	4	0	0	dish	
52	4	0	0	dish	
53	4	0	0	dish	
54	4	0	0	dish	
55	5	0	0	dish	
56	5	0	0	dish	
57	5	0	0	dish	
58	5	0	0	dish	
59	5	0	0	dish	
60	5	0	0	dish	
61	5	0	0	dish	
62	5	0	0	dish	
63	6	0	0	dish	
64	6	0	0	dish	
65	6	0	0	dish	
66	6	0	0	dish	
67	6	0	0	dish	
68	6	0	0	dish	Gully bottom
69	6	0	0	dish	
70	6	0	0	dish	
71	6	0	0	dish	
72	6	0	0	dish	
73	7	0	0	dish	
74	7	0	0	dish	
75	7	15.2	60	dish	
76	7	0	0	dish	
77	7	0	0	dish	
78	7	0	0	dish	
79	7	0	0	dish	
80	7	0	0	dish	
81	7	12.7	60	dish	
82	7	0	0	dish	
83	7	0	0	dish	
84	7	0	0	dish	
85	7	0	0	dish	
86	7	0	0	dish	
87	7	0	0	dish	
88	7	0	0	dish	
89	7	0	0	dish	
90	7	0	0	dish	
91	7	0	0	dish	
92	7	0	0	dish	
93	7	0	0	dish	

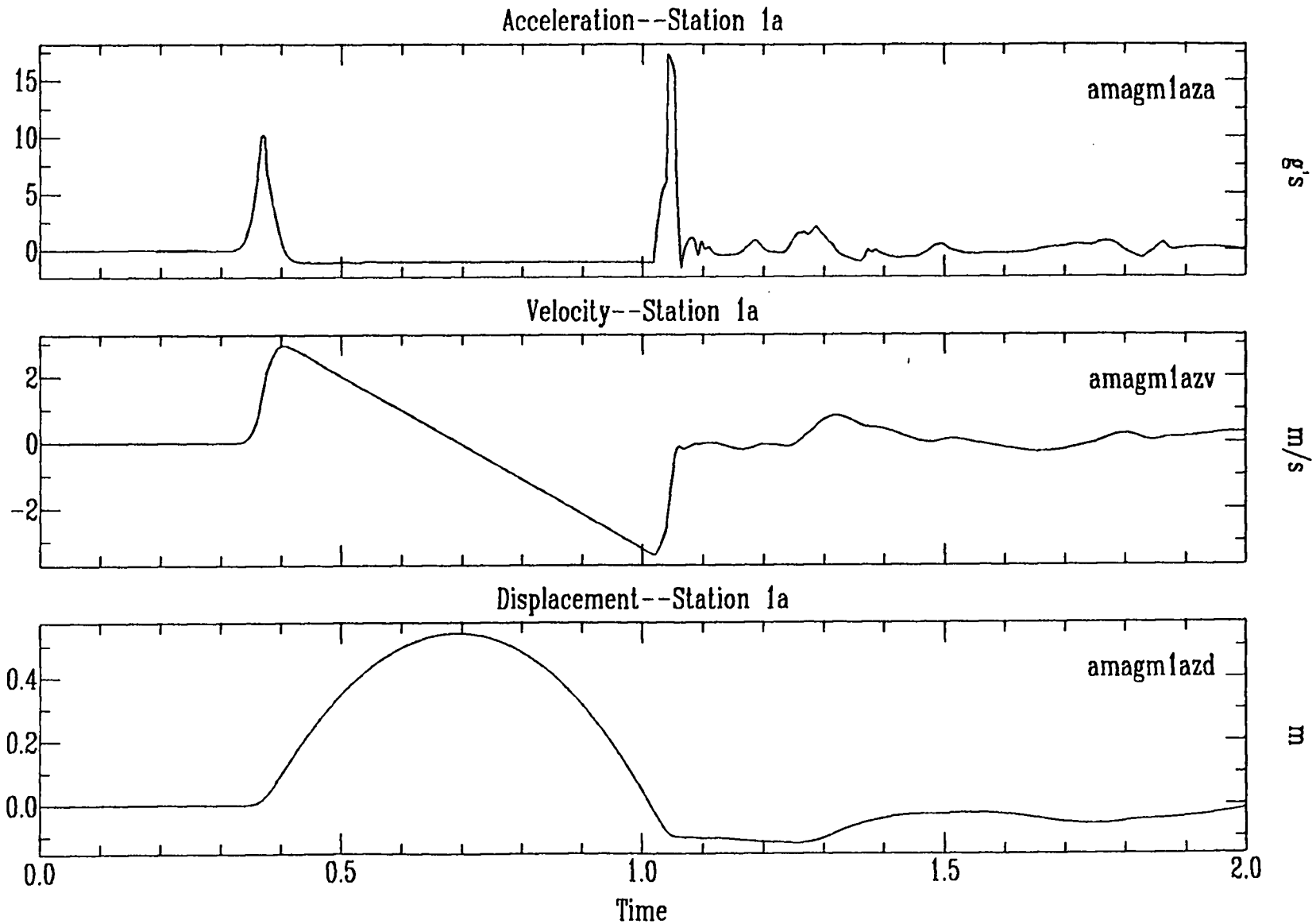
Table 8. Amarillo SIG Results (Continued)

Ball	Array	Movement Dist (cm)	Az	Placement	Comment
94	7	0	0	dish	
95	7	0	0	dish	
96	7	0	0	dish	
97	8	0	0	dish	
98	8	7.6	225	dish	
99	8	0	0	dish	
100	8	0	0	dish	
101	8	7.6	195	dish	
102	8	0	0	dish	
103	8	0	0	dish	
105	9	0	0	dish	
106	9	0	0	dish	
107	9	0	0	dish	
108	9	0	0	dish	
109	9	0	0	dish	
110	9	0	0	dish	
111	9	0	0	dish	
112	9	0	0	dish	
113	9	0	0	dish	
114	9	0	0	dish	
115	10	0	0	dish	
116	10	0	0	dish	
117	10	0	0	dish	
118	10	0	0	dish	
119	10	0	0	dish	
120	10	0	0	dish	
121	10	0	0	dish	
122	0	7.6	315	dish	
123	10	7.6	45	dish	
124	10	0	0	dish	
125	11	0	0	dish	North of Silent Canyon
126	1	0	0	dish	
127	11	0	0	dish	Same dish as Ball #150
128	11	0	0	dish	Same dish as Ball #149
129	11	0	0	dish	Same dish as Ball #148
130	11	0	0	dish	Same dish as Ball #147
131	11	0	0	dish	Same dish as Ball #146
132	11	0	0	dish	Same dish as Ball #145
133	11	0	0	dish	Dish adjacent to Ball #144
134	11	0	0	dish	Dish adjacent to Ball #143
135	11	0	0	dish	Dish adjacent to Ball #142
136	11	0	0	dish	Dish adjacent to Ball #141
137	11	5.1	150	dish	Dish adjacent to Ball #140
138	11	0	0	dish	Dish adjacent to Ball #139
139	11	0	0	dish	Dish adjacent to Ball #138

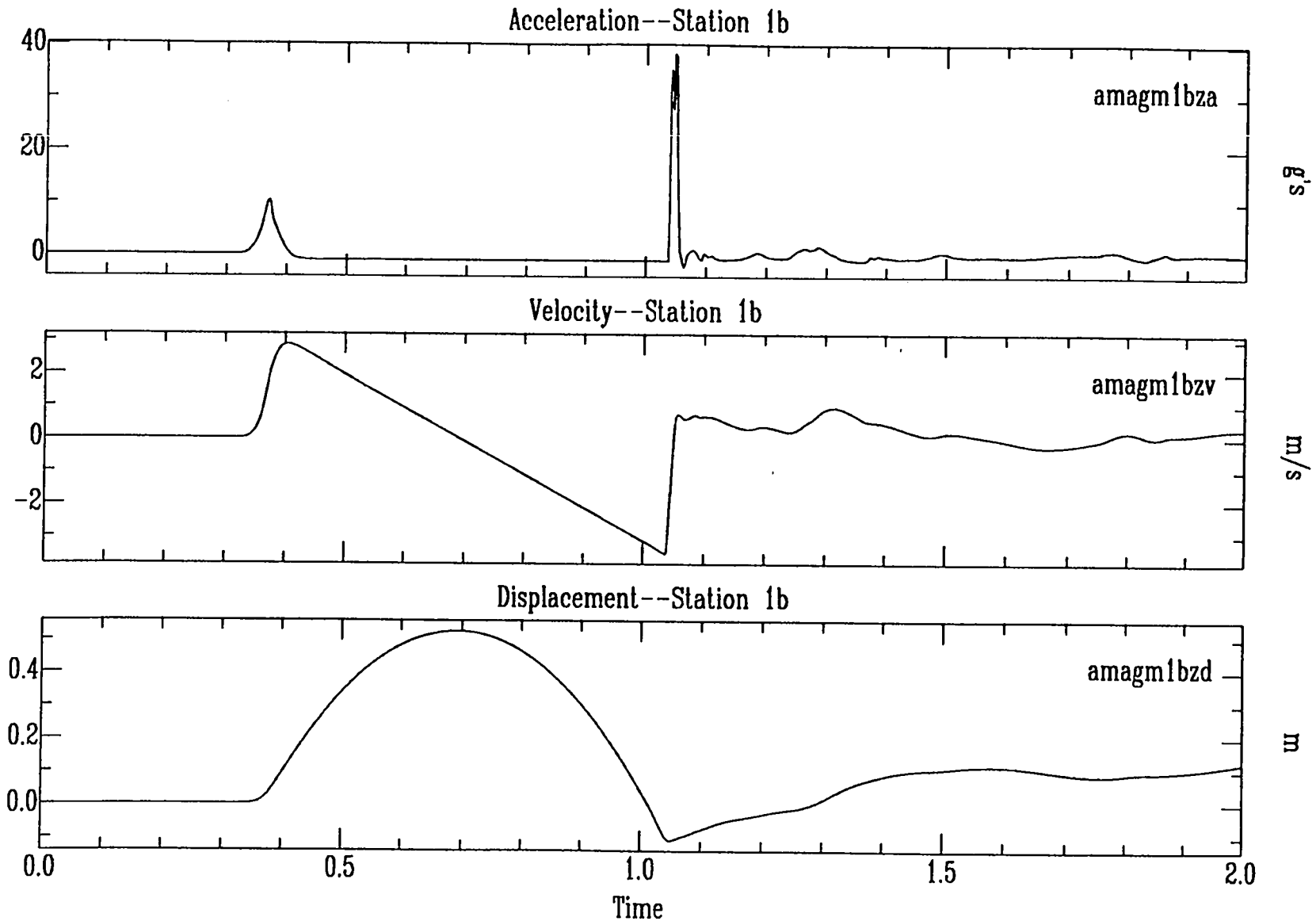
Table 8. Amarillo SIG Results (Concluded)

Ball	Array	Movement Dist (cm)	Az	Placement	Comment
140	11	0	0	dish	Dish adjacent to Ball #137
141	11	2.5	285	dish	Dish adjacent to Ball #136
142	11	0	0	dish	Dish adjacent to Ball #135
143	11	0	0	dish	Dish adjacent to Ball #134
144	11	0	0	dish	Dish adjacent to Ball #133
145	11	0	0	dish	Same dish as Ball #132
146	11	0	0	dish	Same dish as Ball #131
147	11	0	0	dish	Same dish as Ball #130
148	11	0	0	dish	Same dish as Ball #129
149	11	0	0	dish	Same dish as Ball #128

Amarillo Surface Ground Motion



Amarillo Surface Ground Motion



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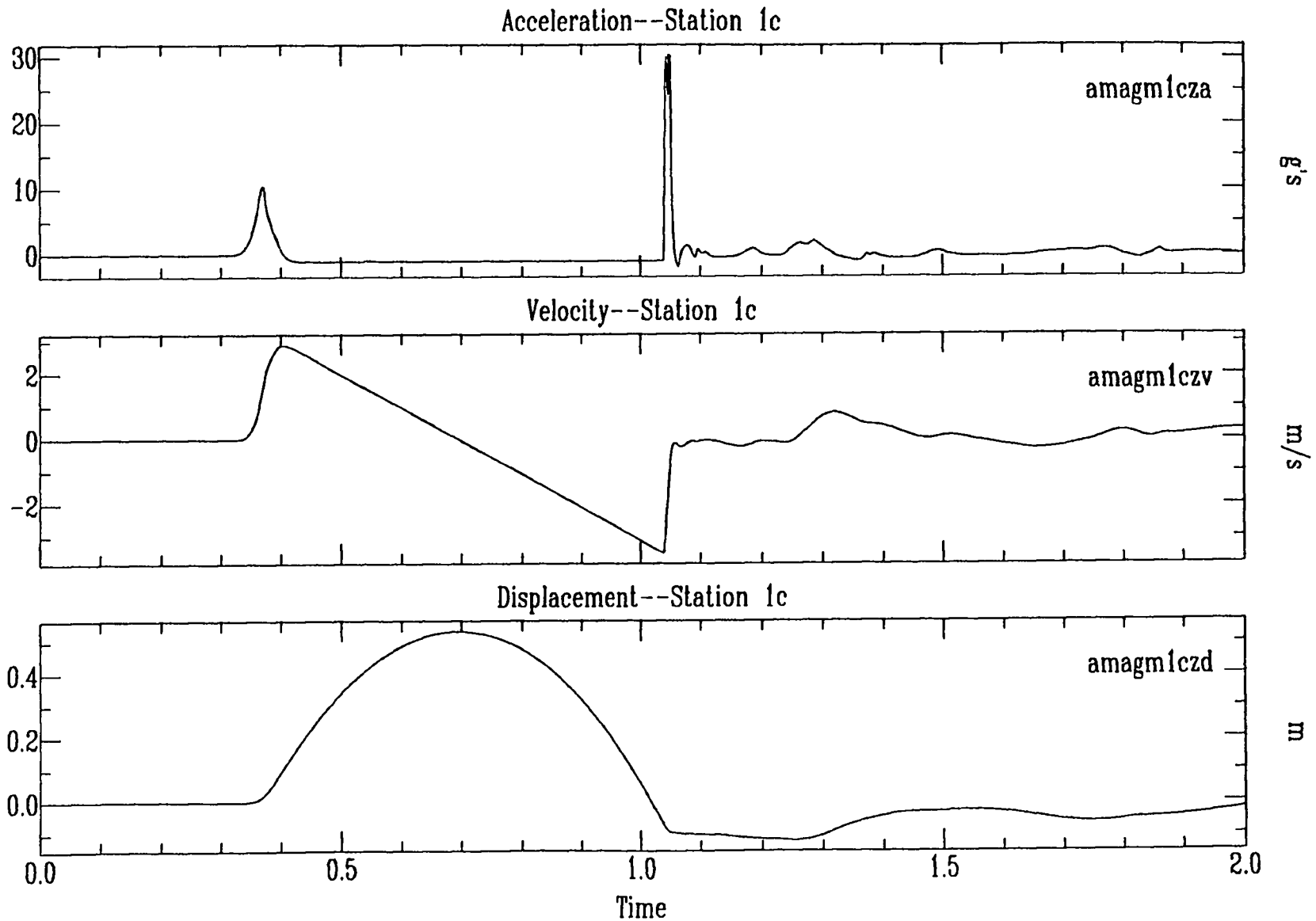

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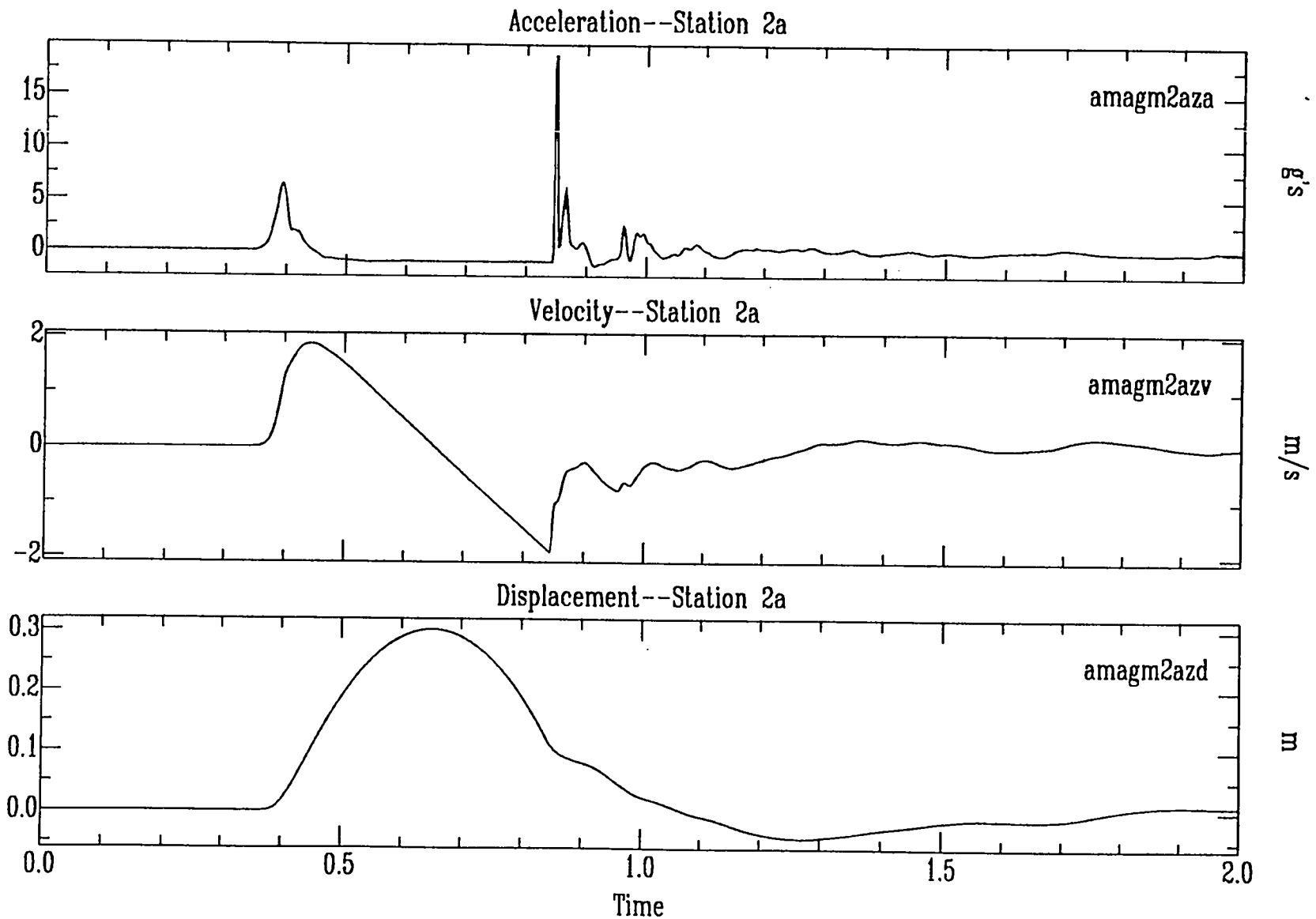

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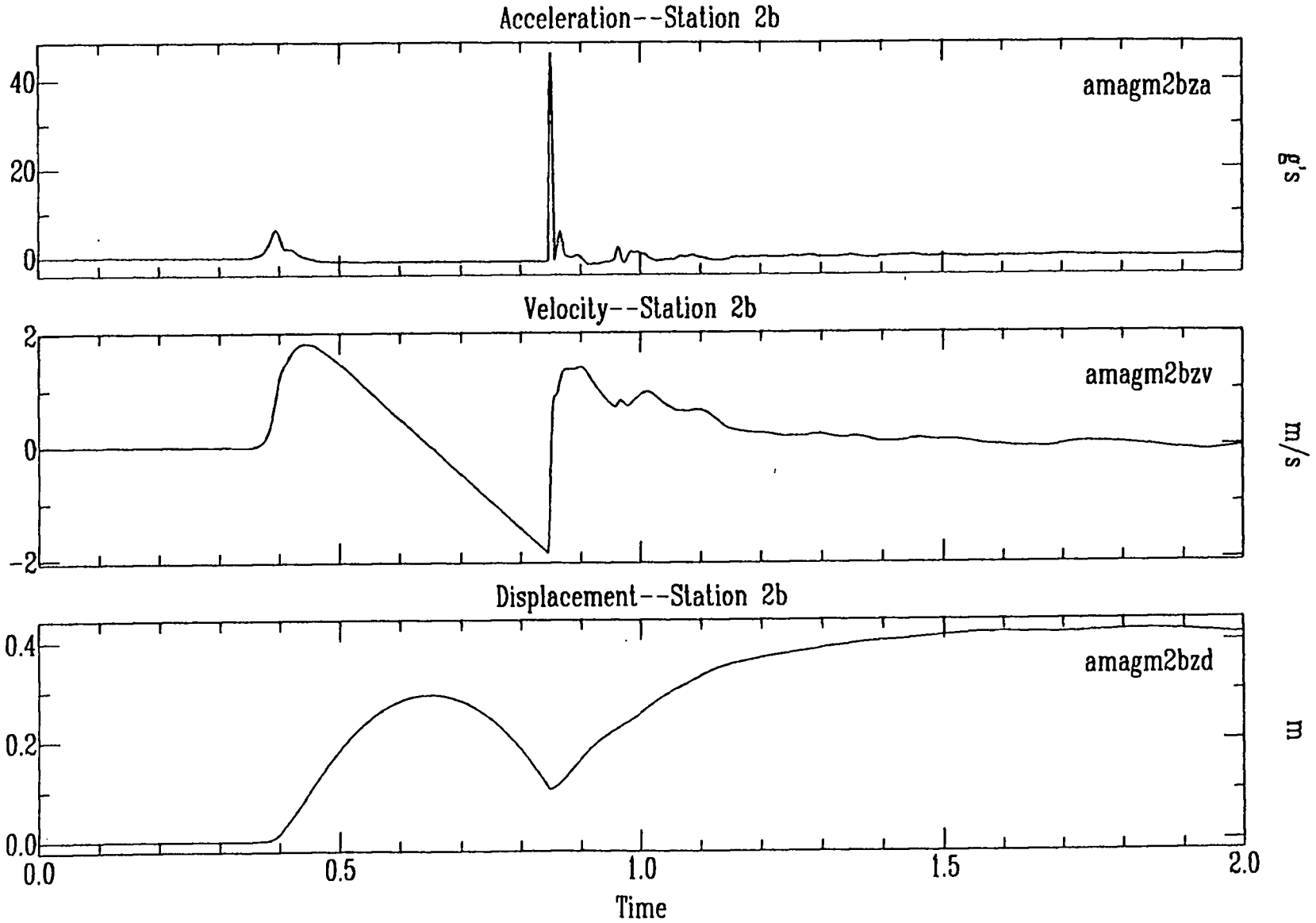

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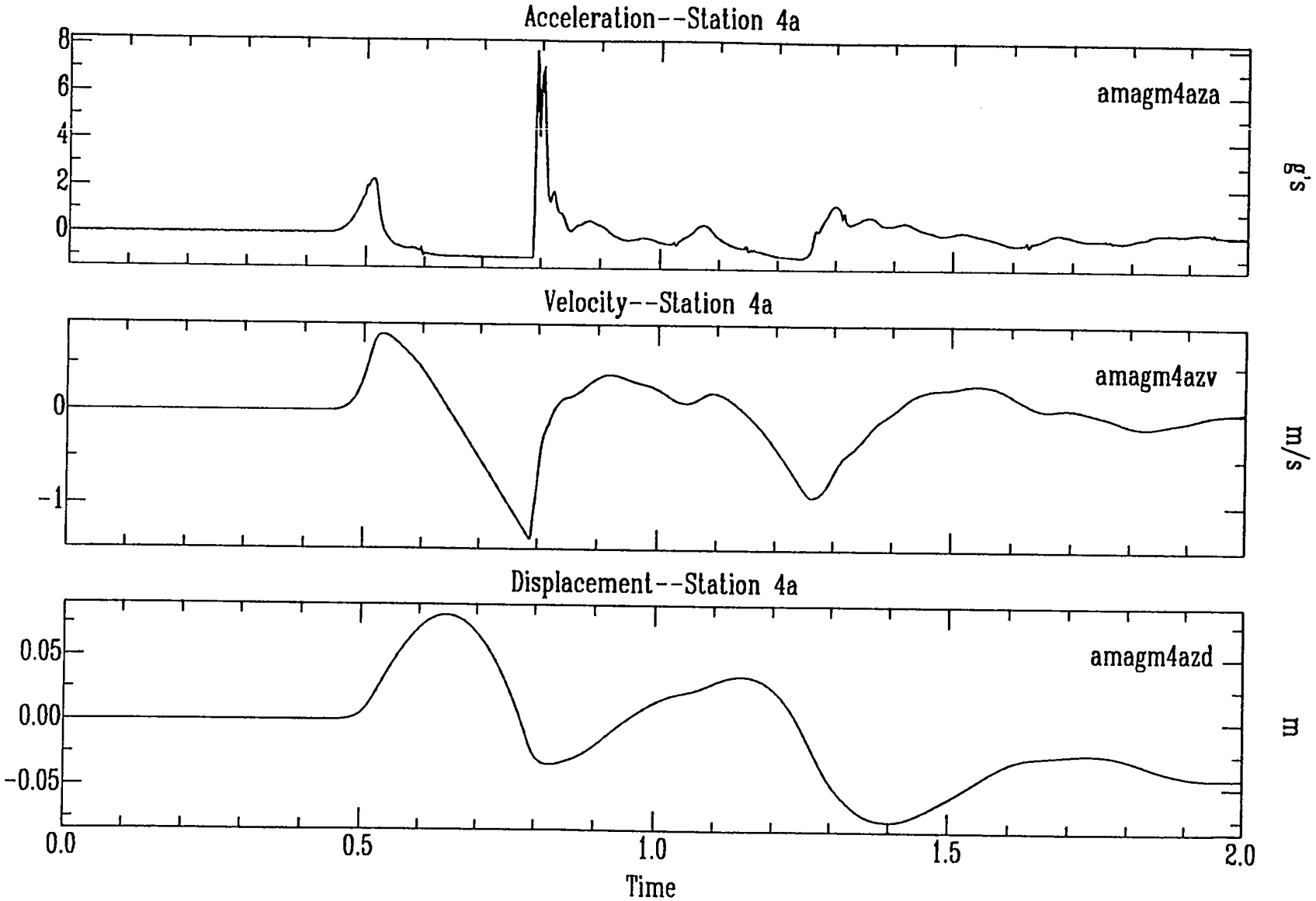

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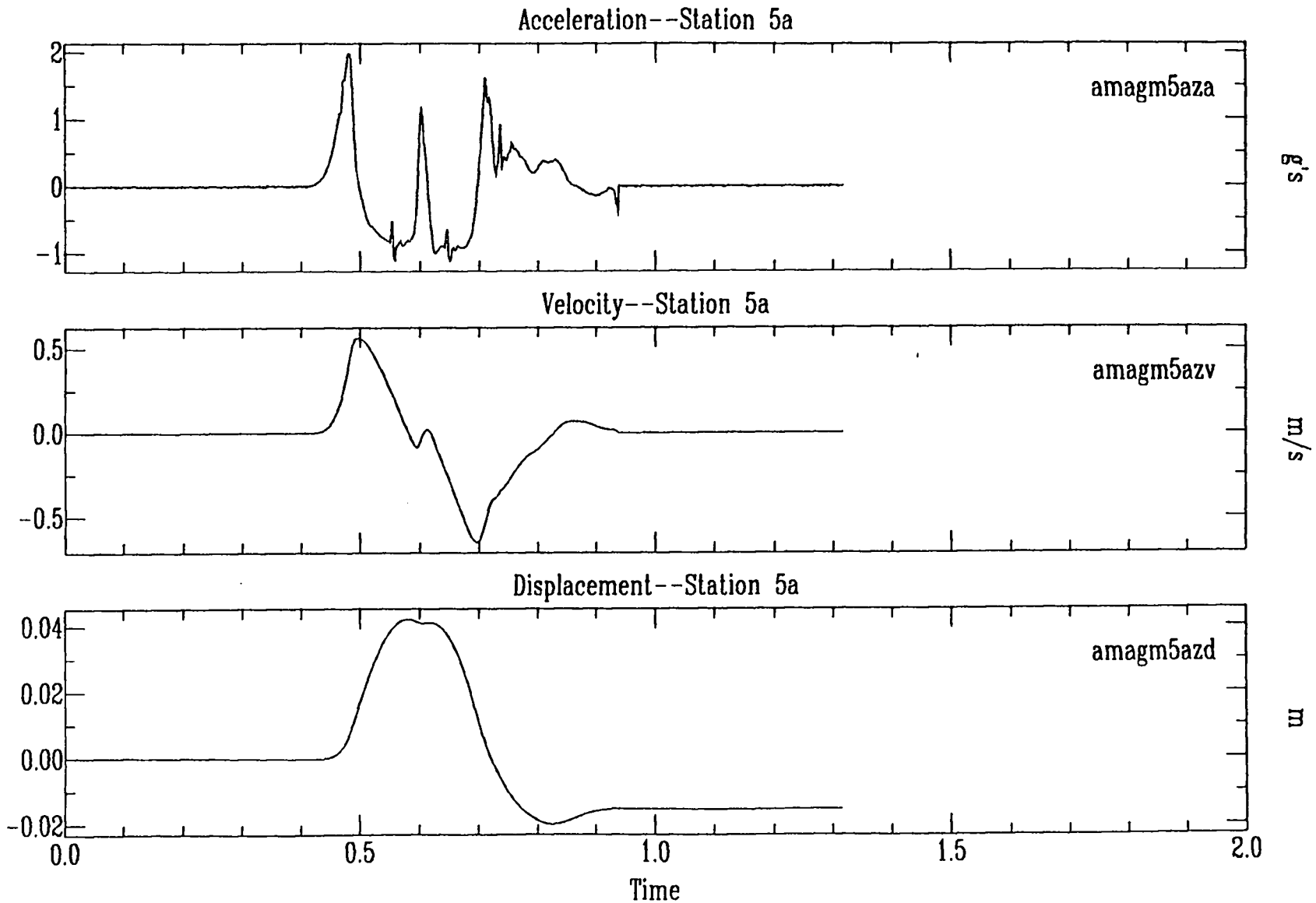

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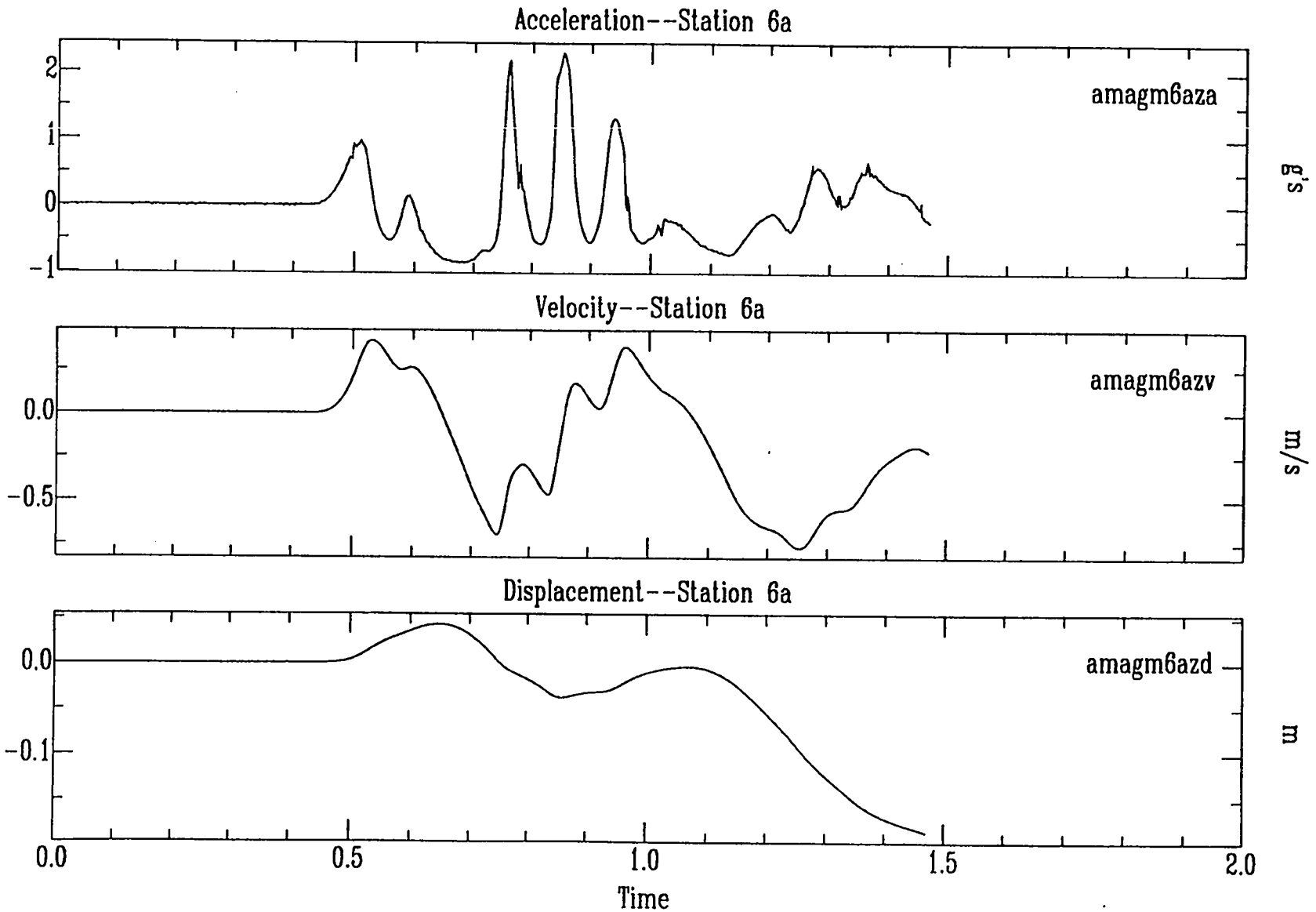


4.6. Hornitos (U20bc)

Experiment design. The only ground-motion measurement made on Hornitos was the SIG experiment. SIGs were deployed at 147 sites on four azimuths. The azimuths and approximate distances are listed in Table 9, which also lists the postshot observations for each SIG. (For easy reference purposes, these four azimuths are called 'north,' 'east,' 'south,' and 'west.') For this experiment, a golf ball was used as the SIG. At each site, a 15.2-cm diameter plastic dish filled with ~2 cm of soil was placed on a level cleared area. The golf ball was centered in the dish. Spacing between sites was approximately 30-40 m (Fig. 10).

SIG results. SIG retrieval was started the afternoon of the event and concluded 2 November 1989. The data from the SIGs are more complex than anticipated. In many cases, just measuring the azimuth and distance the ball moved would ignore much of the data. The soil in the dishes held the traces of the ball rolling. For that reason, the azimuth and distance values in the table usually indicate the total distance the ball rolled on a single azimuth. In addition, the azimuth and distance on which the initial motion occurred are the ones listed in the table, when that could be determined.

In several instances, the ball rolled forward (forward is defined as the direction toward SGZ), then rolled backward (backward is away from SGZ), on the same azimuth. The distance is the length of the track, and the azimuth is the direction from the ball origin to its final position. However, at some time, the ball had to roll the opposite direction, 180° off.

The following is a summary of observations on the SIG movements:

1. Based on SIG data, SGM within the spall zone was not concentric with SGZ. There was no SIG movement west of the Purse fault on the west azimuth (beyond the predicted edge of spall). On the other three azimuths, there was SIG motion at the furthest locations, which were well beyond the predicted edge of spall.
2. SIG movements were significantly different on the northern azimuth than on the other three. Several locations on the north azimuth indicated complex roll patterns, roughly a north-south motion and then an orthogonal east-west motion. On the other three azimuths, rolling was generally on a single azimuth.
3. On the east azimuth SIGs were deployed closer to SGZ than on the other three azimuths. At these closer locations, the SIGs were thrown from their dishes and, at the closest locations, the dishes had moved. None of the dishes were overturned, just moved horizontally. They were probably lofted, as there weren't traces in the dirt of the dishes sliding.
4. All but two of the SIGs at the first 17 locations on the east azimuth were thrown from their dishes. Some factors that may help explain this are: (1) closer

proximity to SGZ; (2) much of this part of the traverse is on a hill between two drainages; and (3) locations E-12 through E-17 are in the vicinity of the second drainage where the preexisting fractures were reactivated. Three of the four SIGs that were thrown out of dishes on the north azimuth are also in fairly close proximity to SGZ. In addition, the north azimuth follows a drainage that is very likely structurally controlled. However, we have no explanation for the SIGs that were thrown out of dishes on the south azimuth. These locations were on a gentle, north-facing slope. We found very few cracks or any type of surface disruption on this slope. In addition, the SIG that moved the most was the furthest location on the south azimuth to be thrown out. It was close to the top of the slope.

5. Initial motion of the SIGs, in general, seems to have been toward SGZ.

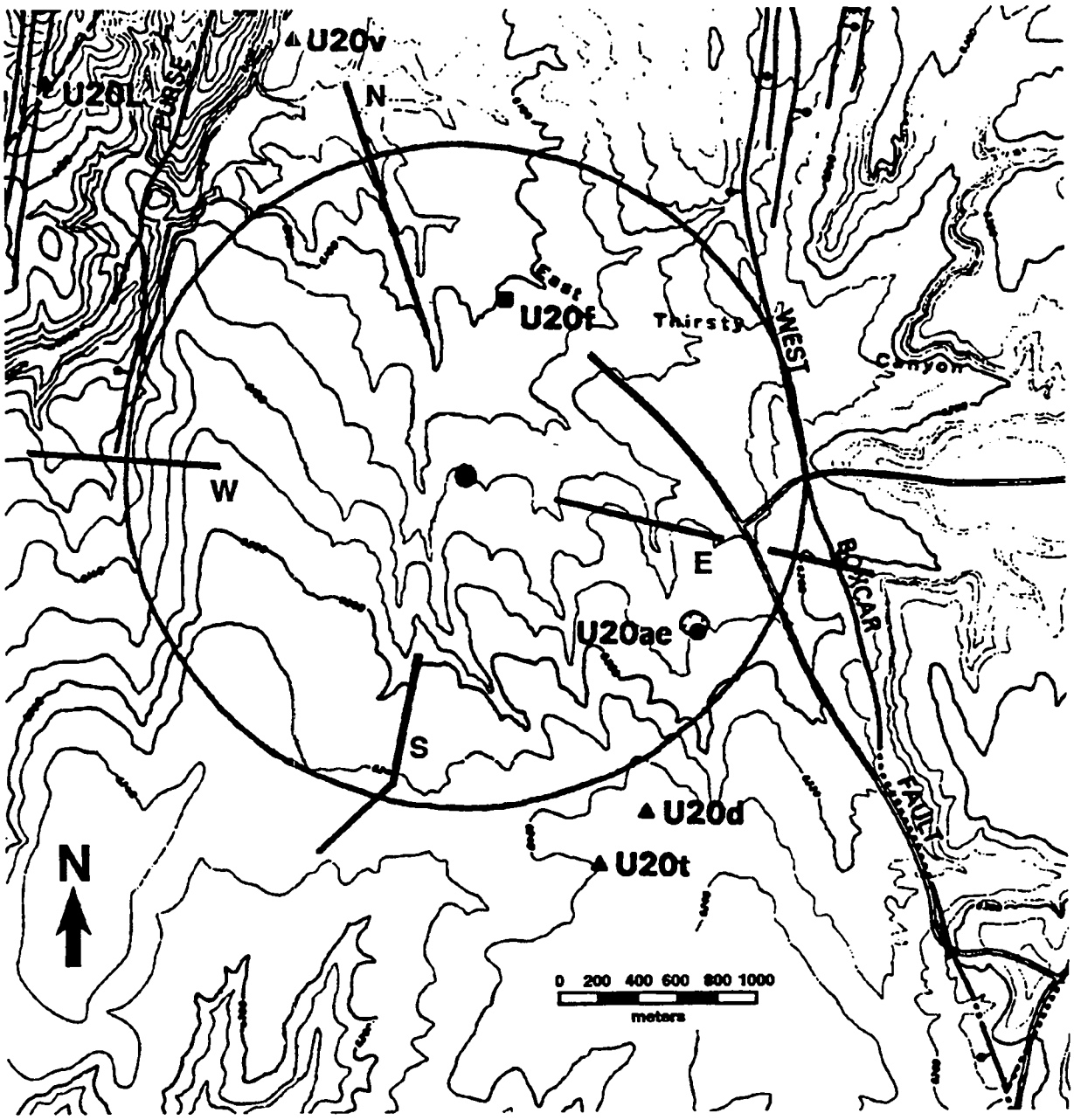


Fig. 10. Hornitos experimental plan.

Table 9. Hornitos SIG Data

Location	Azi from SGZ (deg)	Dist from SGZ (m)	Dist Moved (cm)	Azi Moved (deg)	Comment
E-1	105	457	55.9	145	Dish moved at least 30.5 cm at 165°; ball moved 30.5 cm at 125°from new location of dish.
E-2	105	495	53.3	105	Dish moved ~5.1 cm at 105°; ball moved 48.3 cm from new location of dish.
E-3	105	533	45.7	135	Dish moved 45.7 cm at 105°, ball moved 22.9 cm at 195° from dish.
E-4	105	572	15.2	310	Thrown from dish.
E-5	105	610	43.2	65	Dish moved 12.7 cm at 105°, ball moved 38.1 cm" at 75° from dish.
E-6	105	648	20.3	115	Dish moved 20.3 cm at 115°, ball stayed in dish.
E-7	105	686	30.5	120	Thrown from dish.
E-8	105	724	20.3	135	Thrown from dish. Crack 0.6 m west of dish, heading 40°-220°.
E-9	105	762	33.0	150	Thrown from dish.
E-10	105	800	20.3	135	Thrown from dish, dirt in dish shifted to 135°.
E-11	105	838	40.6	75	Thrown from dish.
E-12	105	876	38.1	110	Thrown from dish. Reactivation of major fracture between E-12 and E-13, heading 355°-10°. Ground disrupted, rocks overturned.
E-13	105	914	7.6	110	Rolled.
E-14	105	953	0	0	
E-15	105	991	17.8	90	Thrown from dish. Reactivated cracks between E-15 and E-16, heading 15°-25°.
E-16	105	1029	15.2	5	Thrown from dish.
E-17	105	1067	20.3	165	Thrown from dish. Dirt in dish shifted to 85°. Numerous reactivated cracks between E-17 and E-18, heading 15°-25°.
E-18	105	1105	0	0	Rolled in dish, ball was shifted, but ended up at origin.
E-19	105	1143	5.1	285	Rolled in dish, ball was shifted, but ended up at origin.
E-20	105	1181	7.6	265	Rolled.
E-21	105	1219	5.1	290	Rolled.
E-22	105	1257	3.8	245	Rolled.
E-23	105	1524	0	0	
E-24	105	1562	2.5	275	Rolled.
E-25	105	1600	0	0	
E-26	105	1638	5.1	275	Movement questionable, rabbit tracks in vicinity.
E-27	105	1676	7.6	110	Rolled.
E-28	105	1715	7.6	245	Rolled.
E-29	105	1753	7.6	255	Rolled back and forth.
E-30	105	1791	2.5	245	Rolled.
E-31	105	1829	15.2	165	Rolled generally back and forth.

Table 9. Hornitos SIG Data (Continued)

Location	Azi from SGZ (deg)	Dist from SGZ (m)	Dist Moved (cm)	Azi Moved (deg)	Comment
E-32	105	1859	17.8	330	Thrown from dish.
E-33	105	1890	3.8	310	Rolled.
E-34	105	1920	0	0	Rolled in dish, ball was shifted, but ended up at origin. Reactivation of fractures on Boxcar fault, general heading 345°. Location: 4.5 m north of E-35, 4.5 m west of E-36, west side of Boxcar fault.
E-35	105	1920	2.5	250	Rolled back and forth. Location: 4.5 m west of E-37, 4.5 m south of E-34, west side of Boxcar fault.
E-36	105	1923	0	0	Rolled in dish, ball was shifted, but ended up at origin. Location: 4.5 m east of E-34, 4.5 m north of E-37, east side of Boxcar fault.
E-37	105	1923	0	0	Rolled in dish, ball was shifted, but ended up at origin. Some indication of motion on heading 65°-245°. Location: 4.5 m east of E-35, 4.5 m south of E-36, east side of Boxcar fault.
E-38	105	1926	0	0	Location: 3 m east of E-37.
E-39	105	1951	7.6	205	Rolled.
E-40	105	1981	7.6	280	Rolled.
S-1	195	1036	12.7	40	Rolled back and forth, general heading 20°-30°.
S-2	195	1067	15.2	25	Rolled back and forth, general heading 15°-35°.
S-3	195	1097	7.6	15	Rolled back and forth in front part of dish.
S-4	195	1128	5.1	15	Rolled back and forth.
S-5	195	1158	7.6	25	Rolled back and forth.
S-6	195	1189	2.5	5	Rolled back and forth.
S-7	195	1219	5.1	55	Rolled back 5.1 cm 235°, forward at 65°, then toward west.
S-8	195	1250	7.6	355	Rolled forward, dirt in dish shifted to back.
S-9	195	1280	10.2	10	Thrown out of dish.
S-10	195	1311	10.2	5	Rolled back and forth.
S-12	195	1341	12.7	5	Rolled back and forth.
S-13	195	1372	20.3	355	Thrown out of dish.
S-14	195	1402	10.2	10	Rolled back and forth.
S-15	195	1433	7.6	0	Rolled back and forth.
S-16	195	1463	3.8	0	Rolled off center, dish shaken, no roll tracks.
S-17	195	1494	15.2	355	Thrown out of dish.

Table 9. Hornitos SIG Data (Continued)

Location	Azi from SGZ (deg)	Dist SGZ m)	Dist Moved (cm)	Azi Moved (deg)	Comment
S-18	195	1524	10.2	15	Rolled back and forth.
S-19	195	1554	15.2	20	Rolled back and forth.
S-20	195	1585	162.6	45	Thrown out of dish.
S-21	195	1615	15.2	5	Rolled back and forth.
S-22	195	1646	15.2	5	Rolled back and forth.
S-23	196	1676	6.4	15	Rolled back and forth.
S-24	196	1707	3.8	15	Rolled forward.
S-25	197	1737	3.8	15	Rolled forward.
S-26	197	1768	6.4	355	Rolled back and forth.
S-27	198	1798	7.6	350	Rolled back and forth.
S-28	198	1829	10.2	355	Rolled back and forth.
S-29	199	1859	8.9	5	Rolled back and forth.
S-30	199	1890	5.1	30	Rolled.
S-31	200	1920	7.6	30	Rolled.
S-32	200	1951	12.7	10	Rolled back and forth.
S-33	200	1981	12.7	20	Rolled back and forth.
S-34	201	2012	10.2	5	Rolled back and forth.
S-35	201	2042	10.2	5	Rolled back and forth.
W-1	275	1250	12.7	135	Rolled back and forth.
W-2	275	1280	7.6	100	Rolled back and forth.
W-3	275	1311	12.7	100	Rolled back and forth; minor cracking 3 m east of dish, heading 15°; crack .6 m west of dish, heading 15°-25°; reactivated crack 3 m west of dish, heading N.
S.W-4	275	1341	12.7	115	Rolled back and forth.
W-5	275	1372	0	0	
W-6	275	1402	3.8	100	Rolled.
W-7	275	1433	0	0	
W-8	275	1463	3.8	285	Rolled backward.
W-9	275	1494	0	0	
W-10	275	1524	0	0	
W-11	275	1554	0	0	
W-12	275	1585	3.8	110	Rolled.
W-13	275	1615	12.7	115	Rolled back and forth.

Table 9. Hornitos SIG Data (Continued)

Location	Azi from SGZ (deg)	Dist SGZ (m)	Dist Moved (cm)	Azi Moved (deg)	Comment
W-14	275	1646	1.3	140	Rolled. Reactivation of old fracture 9 m east of dish, heading 0°.
W-15	275	1676	0	0	
W-19	275	1737	0	0	
W-16	275	1707	0	0	
W-17	275	1707	0	0	Location: 1.5 m south of W-16, east side of Purse fault.
W-18	275	1710	0	0	Location: 6 m west of W-16, west side of Purse fault.
W-20	275	1768	0	0	20 m west of W-20-hairline crack on old pressure ridge, but animal burrow 3m north not affected.
W-21	275	1798	0	0	
W-22	275	1829	0	0	
W-23	275	1859	0	0	
W-24	275	1890	0	0	
W-25	275	1920	0	0	
W-26	275	1951	0	0	
W-27	275	1981	0	0	
W-28	275	2012	0	0	
W-29	275	2042	0	0	
W-30	275	2073	0	0	
W-31	275	2103	0	0	
W-32	275	2134	0	0	
W-33	275	2164	0	0	
W-34	275	2195	0	0	
W-35	275	2225	0	0	
N-1	345	762	12.7	325	Thrown out of dish.
N-2	345	800	0	0	Major fracture 4.5 m north of dish not reactivated (300°).
N-3	345	838	12.7	280	Thrown out of dish. Minor reactivation of major fracture 2.5 m south of dish.
N-4	345	876	2.5	140	Rolled.
N-5	345	914	5.1	355	Dirt shifted in dish toward 280°.
N-6	345	953	2.5	310	Rolled.
N-7	345	991	10.2	350	Thrown out of dish; dirt in dish shifted.
N-8	345	1029	10.2	350	Rolled back and forth on 350° azimuth, then rolled heading 235°, and stopped at edge. Crack 3 m north of dish into gully bottom and up the other side, heading 75°-125°. Lost crack in the rocks.

Table 9. Hornitos SIG Data (Continued)

Location	Azi from SGZ (deg)	Dist from SGZ (m)	Dist Moved (cm)	Azi Moved (deg)	Comment
N-9	345	1067	7.6	165	Rolled forward.
N-10	345	1105	7.6	0	Rolled backward (downslope). Rock slide 6 m north of dish.
N-11	345	1143	10.2	280	Thrown out of dish.
N-12	345	1181	7.6	115	Rolled forward to edge of dish, then rolled along edge of dish both E and W.
N-13	345	1219	7.6	160	Rolled forward to edge of dish, then rolled along edge of dish both E and W. Crack halfway between. N-13 and N-14, at 215°.
N-14	345	1257	2.5	180	Rolled forward, then side to side. Crack 3 m north of dish, discontinuous, general heading 355°.
N-15	345	1295	15.2	205	Rolled back and forth on heading 205°, then to the southeast. Final offset 7.6 cm at 140°.
N-16	345	1334	7.6	225	Roll pattern in dirt disrupted some. Initial motion may be on 165°-345° azimuth.
N-17	345	1372	15.2	170	Rolled back and forth full 15.2 cm. Final offset 6.4 cm at 170°. Crack halfway between N-16 and N-17. 3 m from edge of gully.
N-18	345	1410	3.8	45	Rolled. Location: in the bottom of a gully.
N-19	345	1448	10.2	165	Rolled back and forth. Some orthogonal motion toward the NE.
N-20	345	1486	12.7	350	Rolled forward then in an arc toward the east to the back edge of dish. Final offset 7.6 cm at 350°.
N-21	345	1524	5.1	160	Rolled forward then back to center. Location: 4.5 m east (85°) of N-22.
N-22	345	1524	7.6	330	Rolled back.
N-23	345	1562	7.6	325	Rolled backward 7.6 cm at 325°, then along edge of dish to 235°. Located 9 m east of N-24, on hard. rock outcrop.
N-24	345	1562	7.6	150	Rolled back and forth.
N-25	345	1600	2.5	160	Rolled.
N-26	345	1638	7.6	295	Roll pattern partially disrupted; some rolling on azimuth 150°-330°. Cracks 3 m north of dish, general. heading 50° along gully bottom; crack spacing 4.5 m from each other.
N-27	345	1676	2.5	180	Unknown roll pattern.
N-28	345	1715	2.5	335	Rolled backward.
N-29	345	1753	0	0	
N-30	345	1791	5.1	235	Strange roll pattern: segment 2.5 cm at 150°, at each end of this segment, a 5.1 cm arc orthogonal toward the west. Final offset 5.1 cm at 235°.

Table 9. Hornitos SIG Data (Concluded)

Location	Azi from SGZ (deg)	Dist SGZ m)	Dist Moved (cm)	Azi Moved (deg)	Comment
N-31	345	1829	0	0	Very minor hairline cracks on major fractures located 1.5 m northwest of dish, heading 350°.
N-32	345	1867	7.6	160	Two roll segments: 7.6 cm at 160°, then orthogonal set 7.6 cm at 225° (final position). Roll tracks cross. Crack heading 340° close to dish.
N-33	345	1905	10.2	220	Strange roll pattern: 10.2 cm at 220°, 5.1 cm at 325°, and 3.8 cm at 285° (final position).
N-34	345	1943	0	0	
N-35	345	1981	0	0	Small crack heading 45°, 0.3 m west of dish.
N-36	345	2019	12.7	180	Rolled back and forth.
N-37	345	2057	10.2	195	Rolled back and forth.

4.7. Metropolis (U2gg)

Experiment design. To better define a spall zone and its motions, two separate spall-zone experiments were performed on Metropolis. A polar grid, centered on SGZ, was drawn to serve as a starting point for locations of the two experiments. The actual deployment locations are drawn on Figure 11. Instrumentation lines are approximately every 30° of azimuth, and the distance between circle nodes is approximately 150 m.

Of a possible 108 nodes, 71 were accessible to install arrays (see Table 10). Arrays were also installed at each of the accelerometer locations, even those not at nodes, to provide a method of comparing the movements of the balls to the quantitative measurements taken by the accelerometers.

SIG Experiment. For one experiment, a SIG array of 1-in. steel balls and golf balls was placed at each node of the array that was accessible. Although ball arrays cannot give quantitative data on SGM, they can give a more spatially complete characterization of ground motions throughout the spall zone. Analysis of ball motions (sometimes limited to their final resting places) can give some qualitative measure of how the surface reacted to the ground shock: (1) Is the shock impulsive enough to 'launch' the balls? (2) If the balls do not leave the ground, do they show preferential movement, e.g., away from SGZ? (3) Are the surface motions, as evidenced by ball displacements, at a given distance from SGZ of the same magnitude?

A SIG array consisted of 5 steel balls and 2 golf balls, placed in a cross (one crossbar was oriented along the azimuth to SGZ and the other perpendicular). One steel ball and the golf balls were placed at the intersection of the two crossbars, and a steel ball was placed at the end of each 10-m arm. An 8-cm nail was placed under each ball to mark its starting position. In the middle, the steel ball was set on a 25-cm spike, one golf ball was set on a nail, and the other was placed in a 15-cm plastic dish, partially filled with soil, and attached to the ground by a nail. The steel balls were color-coded in order to be able to track their movement: white in the middle, red toward SGZ, blue away from SGZ, orange to the left (when facing SGZ), and green to the right.

Accelerometer Experiment. The second spall zone experiment involved placing 19 triaxial, force-balanced accelerometer packages about 150 m inside of and 150 m outside of the predicted edge of spall (ESA measurements). These quantitative results on the edge of spall were to be compared directly with the results of the SIG experiment and with the predictions of the limit of spall.

These experiments were designed to map and characterize ground motion in the spall zone and determine its limits. Some of the questions that these experiments were to address are: (1) Is the spall zone circular? (2) Is the energy in the spall zone equally partitioned? (3) Does the transition from spall to no spall have any distinctive characteristics? (4) Does a collapse chimney in close proximity to an explosion

capture/attenuate the shock wave? Which signals are affected: surface effects, local ground motion, regional seismic? (5) Does a fault, like the Yucca system, capture/reflect/attenuate the shock wave, and which signals are affected?

In addition to the spall-zone definition experiments, GRMPY fielded 14 stations inside the predicted spall zone.

In Figure 11, stations with solid circles had SIG arrays only; stations denoted by an "F" had a SIG array *and* an FBA package; stations denoted by a "G" had only a GRMPY station.

SIG Results. Observations of the SIG arrays began about 3 hours after zero time. The ball arrays at 9-8, 9-7, 8-8, 10-8, 11-8, 12-8 were recorded Saturday, the day of the event. High winds and blowing dust caused fieldwork to be stopped early. Fieldwork was not possible Sunday because of the extremely poor weather conditions. During the following two days, all of the ball arrays were visited and the movements noted. The order in which each location was visited is usually considered very important. However, because most of the subtle effects were significantly altered and obliterated by the weather (i.e., the tracks of the balls rolling on the ground), the chronology is not a factor when analyzing the surface effects data.

In most cases, the balls apparently did not get enough of an impulse from the ground shock to be "launched," i.e., the balls apparently just rolled around on the surface of the ground. At a couple locations, the ground around the array was extremely disrupted. Figure 12 attempts to graphically depict the motions observed. These data are listed in Table 11.

Accelerometer Results. As noted in the section describing ESA measurements, the arrival times for these measurements are not accurate due to the drift in the internal clocks of the digital recorders. Nineteen stations were fielded with portable digital recorders (REFTEKs); GRMPY fielded 14 stations of which seven appear to have been collocated. All of the GRMPY stations appear to have spalled, but only nine of nineteen ESA stations appear to have spalled (METSG3A, 3B, 4A, 4B, 7A, 7B, 8A, 9A and 10A) and of these, four appear to have been right at the edge of spall (4A, 4B, 7A and 8A). The edge of spall as defined by the 1-g vertical acceleration limit, from the accelerometer records, is depicted graphically in Figure 13. Note that the spall zone for Metropolis is not circular, and appears to extend outside the predicted zone along the Yucca fault and contract inside the prediction south and northwest of SGZ. Figure 14 (29 pages) contains the data traces for the accelerometer data.

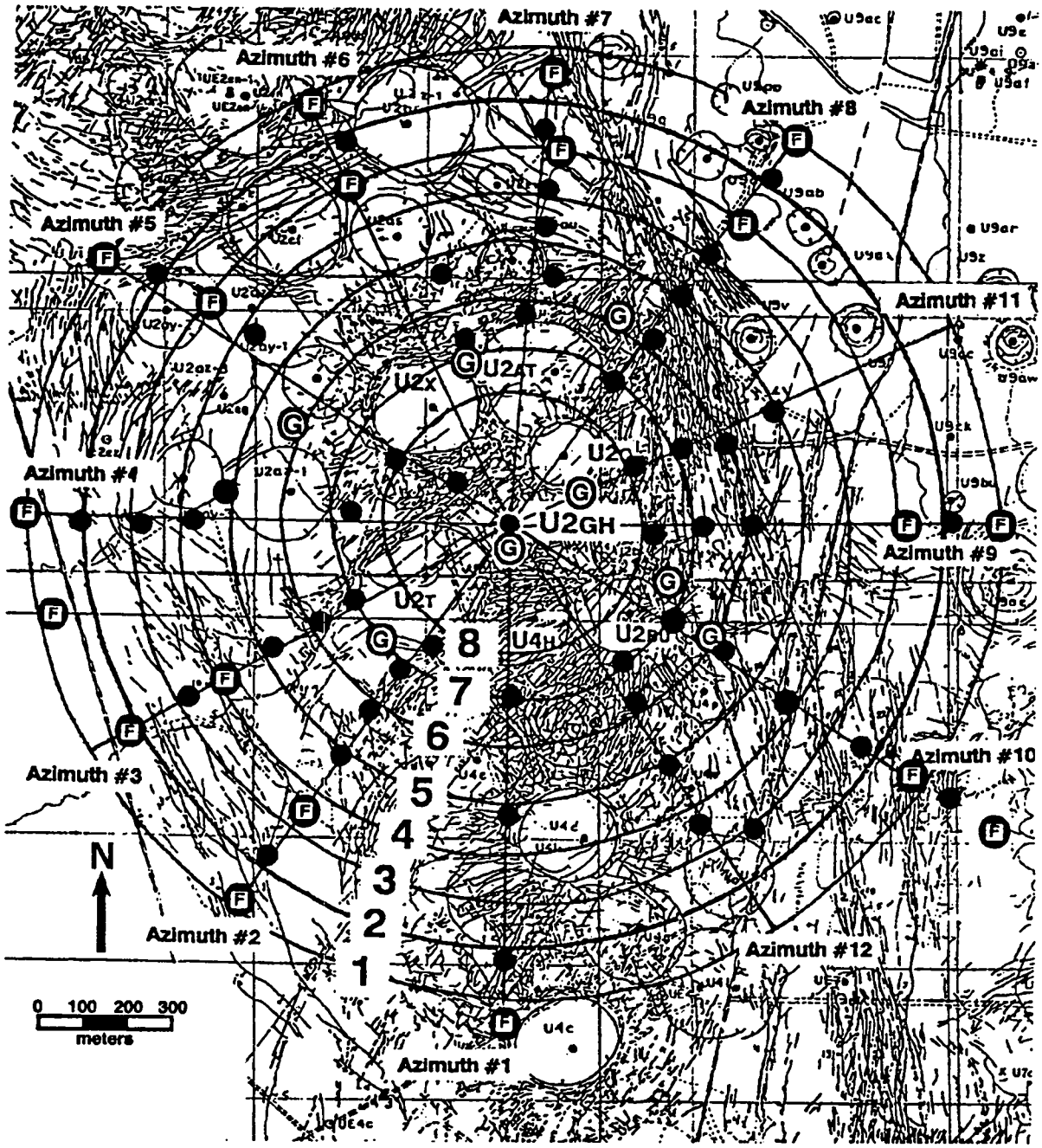


Fig. 11. Metropolis deployment locations.

Table 10. Metropolis Ground Motion Station Data

Station Name	Station Loc U2gh	Accelerometer	Northing (m) 262279	Easting (m) 206746	Slant Range 469 (m) DOB	TOA
METGR1A	15 m S	Endevco 25 g	262266	206745	469	
METGR2A	230 m N61E	Endevco 25 g	262388	206948	522	0.285
METGR3A	686 m N27E	Endevco 25 g	262890	207056	830	0.466
METGR4A	457 m S78E	Endevco 25 g	262184	207192	654	0.359
METGR5A	474 m N17W	Endevco 25 g	262734	206610	667	0.393
METGR6A	476 m S47W	Endevco 25 g	261953	206398	669	0.387
METGR7A	686 m S59E	Endevco 25 g	261930	207335	830	0.458
METGR8A	681 m N64W	Endevco 25 g	262578	206133	827	0.471
METGR9A	686 m N27E	Endevco 25 g	262890	207056	830	0.467
METGR9B	686 m N27E	Endevco 25 g	262890	207056	830	0.47
METGR9C	686 m N27E	Endevco 25 g	262890	207056	830	0.466
METGR10A	686 m N27E	Endevco 25 g	262890	207056	830	0.468
METGR10B	686 m N27E	Endevco 25 g	262890	207056	830	0.465
METGR10C	686 m N27E	Endevco 25 g	262890	207056	830	0.46
METSG1B	1160 m S	Terra Tec 5.28 g	261119	206746	1251	2.52
METSG2A	810 m S35W	Terra Tec 3.7 g	261615	206281	937	2.536
METSG2B	1070 m S35W	Terra Tec 5.28 g	261403	206132	1168	2.587
METSG3A	745 m S60W	Terra Tec 3.7 g	261569	206519	881	2.512
METSG3B	994 m S60W	Terra Tec 5.28 g	261781	205884	1100	2.553
METSG4A	1100 m S89W	Terra Tec 3.7 g	262260	205646	1196	2.552
METSG4B	1060 m N78W	Terra Tec 5.28 g	262059	205709	1159	2.578
METSG5A	845 m N53W	Terra Tec 3.7 g	262788	206071	967	2.401
METSG5B	1100 m N56W	Terra Tec 5.28 g	262894	205834	1196	2.456
METSG6A	860 m N25W	Terra Tec 3.7 g	263058	206383	979	2.526
METSG6B	1175 m N25W	Terra Tec 5.28 g	263344	206249	1265	2.579
METSG7A	880 m N7E	Terra Tec 3.7 g	263152	206853	997	2.468
METSG7B	1055 m N5E	Terra Tec 5.28 g	263330	206838	1155	2.512
METSG8A	875 m N37E	Terra Tec 3.7 g	262978	207273	993	2.519
METSG8B	1105 m N36E	Terra Tec 5.28 g	263173	207396	1201	2.583
METSG9A	890 m E	Terra Tec 3.7 g	262279	207636	1006	2.465
METSG9A	890 m E	Terra Tec 3.7 g	262279	207636	1006	2.465

Table 10. Metropolis Ground Motion Station Data (Concluded)

Station Name	Station Loc U2gh	Accelerometer	Northing (m) 262279	Easting (m) 206746	Slant Range 469 (m) DOB	TOA
METSG9B	1095 m E	Terra Tec 5.28 g	262279	207841	1191	2.525
METSG10A	1085 m S57E	Terra Tec 3.7 g	262870	207656	1182	2.486

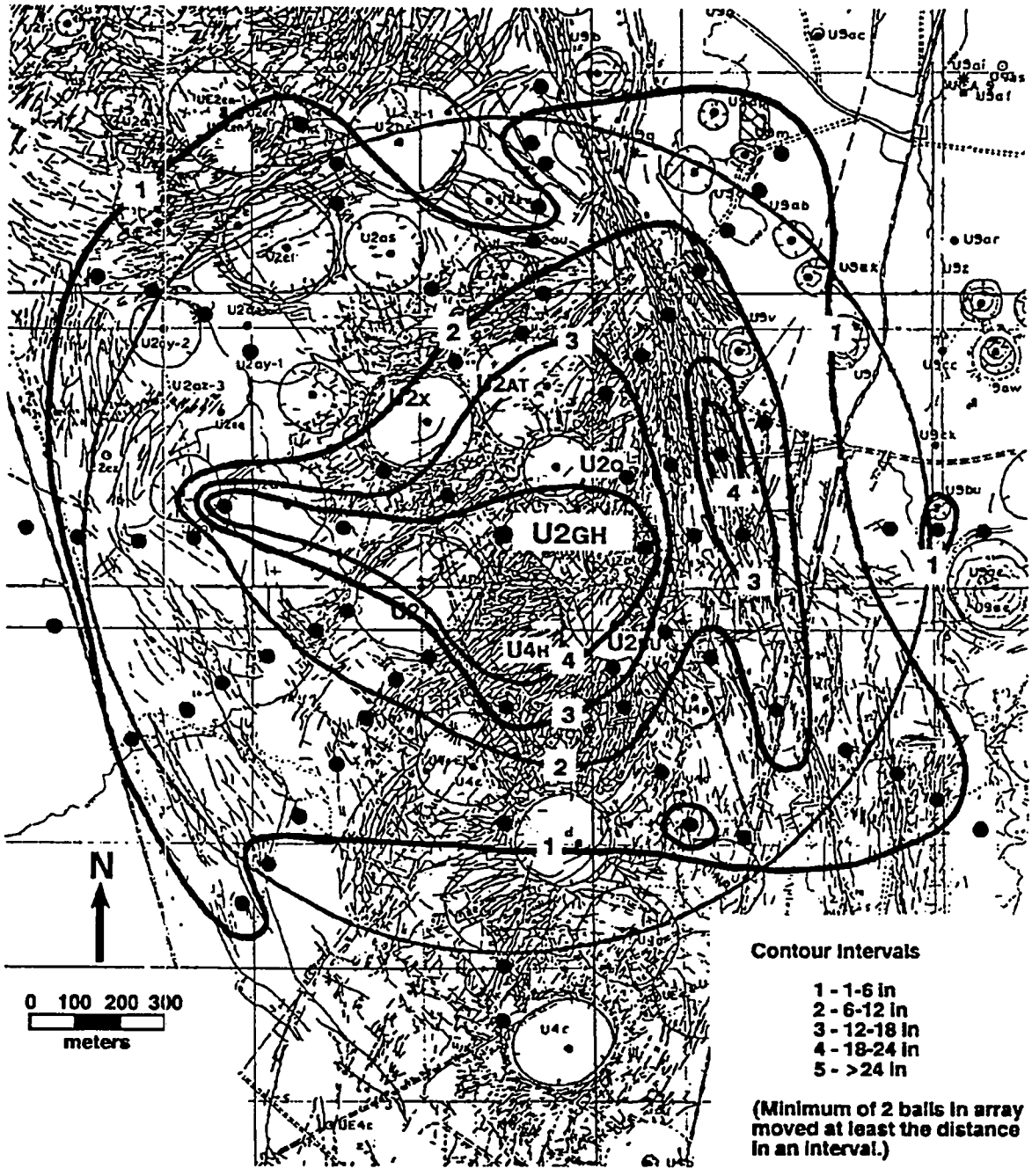


Fig. 12. Results of the SIG experiment on Metropolis. Note that the motion patterns are not concentric around SGZ but appear to be influenced by the Yucca Fault.

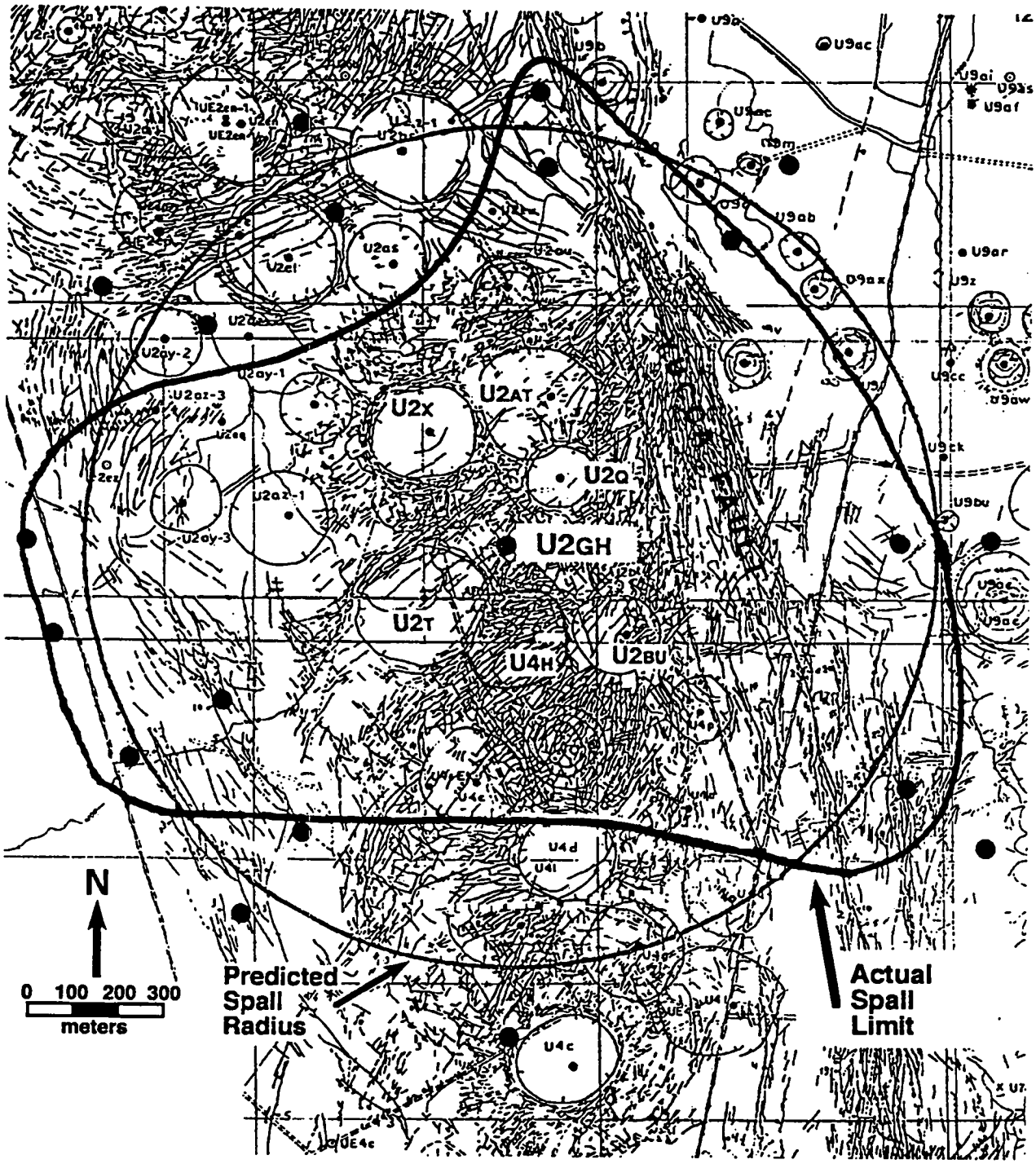


Fig. 13. Spall limit on Metropolis as determined from the extended accelerometer array data.

Table 11. Metropolis SIG Results

Location	Golf Balls In Dish Dist	Golf Balls In Dish Azi	Golf Balls Out Dist	Golf Balls Out Azi	Steel Balls Red Dist	Steel Balls Red Azi	Steel Balls White Dist	Steel Balls White Azi	Steel Balls Blue Dist	Steel Balls Blue Azi	Steel Balls Green Dist	Steel Balls Green Azi	Steel Balls Orange Dist	Steel Balls Orange Azi	Comments
1-1	0	0			0	0	0	0	0	0	0	0	0	0	
1-2	0	0			***	***	0	0	0	0	0	0	0	0	
1-5	0	0	14.0	335	3.8	345	0	0	2.5	105	10.2	345	0	0	Ball in dish rolled, but ended up at origin
1-7	81.3	335	34.3	5	15.2	60	30.5	355	30.5	340	3.8	95	24.1	355	Many reactivated fractures
2-1	0	0			7.6	60	5.1	70	10.2	60	5.1	125	0	0	Several cracks heading 345°-15°
2-2	0	0			0	0	***	***	0	0	12.7	300	0	0	
2-3	0	0	0	0	10.2	175	0	0	0	0	7.6	95	0	0	
2-4	5.1	40	5.1	35	10.2	95	7.6	15	10.2	150	7.6	135	15.2	90	Cracks reactivated
2-5	5.1	190	11.4	45	***	***	7.6	325	14.0	80	8.9	155	8.9	105	Minor reactivation of cracks; crack close to dish and blue ball
2-6	40.6	160	27.9	225	5.1	270	10.2	315	17.8	165	17.8	150	15.2	210	Several cracks reactivated heading 45°, crack close to blue ball
2-7	25.4	45	27.9	170	34.3	85	15.2	135	24.1	85	17.8	95	8.9	70	Numerous cracks
3-1	5.1	115			2.5	215	0	0	0	0	0	0	0	0	
3-2	0	0			0	0	6.4	115	12.7	120	3.8	255	15.2	180	Ball in dish rolled, but ended up at origin
3-3	0	0	15.2	160	8.9	285	7.6	135	3.8	160	10.2	105	3.8	215	Ball in dish rolled, but ended up at origin
3-4	15.2	150	12.7	315	5.1	175	5.1	45	12.7	80	8.9	245	12.7	130	
3-5	21.6	240	44.5	75	19.1	170	12.7	45	26.7	200	5.1	330	17.8	195	

Table 11. Metropolis SIG Results (Continued)

Location	Golf Balls In Dish Dist	Golf Balls In Dish Azi	Golf Balls Out Dist	Golf Balls Out Azi	Steel Balls Red Dist	Steel Balls Red Azi	Steel Balls White Dist	Steel Balls White Azi	Steel Balls Blue Dist	Steel Balls Blue Azi	Steel Balls Green Dist	Steel Balls Green Azi	Steel Balls Orange Dist	Steel Balls Orange Azi	Comments
3-6	26.7	90	24.1	80	7.6	65	19.1	295	17.8	40	10.2	240	25.4	10	
4-1	0	0			24.1	325	0	0	0	0	0	0	0	0	
4-1S	0	0			0	0	0	0	0	0	0	0	0	0	
4-2	0	0			16.5	275	5.1	255	0	0	0	0	5.1	245	
4-3	7.6	245	12.7	175	10.2	245	11.4	225	8.9	50	7.6	0	17.8	90	
4-4	7.6	305	7.6	135	7.6	105	16.5	270	11.4	305	7.6	25	12.7	185	
4-5	15.2	105	8.9	355	***	***	***	***	50.8	310	48.3	120	***	***	Area totally disrupted; no nails for red, white ball locations
4-7	48.3	275	40.6	285	3.8	220	50.8	265	33.0	290	45.7	300	43.2	285	Red ball may have rolled back and forth
5-1	2.5	145			2.5	350	0	0	5.1	315	0	0	2.5	130	Ball may have rolled around in dish
5-2	5.1	95			5.1	15	0	0	8.9	70	6.4	210	7.6	210	
5-3	0	0	8.9	155	0	0	5.1	45	5.1	300	12.7	205	3.8	55	White ball rolled into small depression
5-4	7.6	90	10.2	155	8.9	110	2.5	40	0	0	2.5	195	7.6	150	
5-7	10.2	295	25.4	320	***	***	16.5	220	10.2	210	11.4	305	12.7	240	
5-8	83.8	340	35.6	270	43.2	310	20.3	230	38.1	50	43.2	285	43.2	345	Array close to drillback pad
6-1	2.5	265			0	0	0	0	0	0	3.8	175	12.7	270	
6-2	2.5	325			6.4	130	3.8	285	2.5	240	2.5	180	3.8	205	
6-3	2.5	345	6.4	260	3.8	105	2.5	350	0	0	20.3	185	5.1	285	
6-5	3.8	0	15.2	355	5.1	100	7.6	45	5.1	260	10.2	330	20.3	5	
6-6	2.5	50	22.9	345	5.1	130	***	***	7.6	100	25.4	0	6.4	75	
7-1	0	0			***	***	0	0	0	0	19.1	235	0	0	Red ball gone, flag and nail pulled out of ground

Table 11 Metropolis SIG Results (Continued)

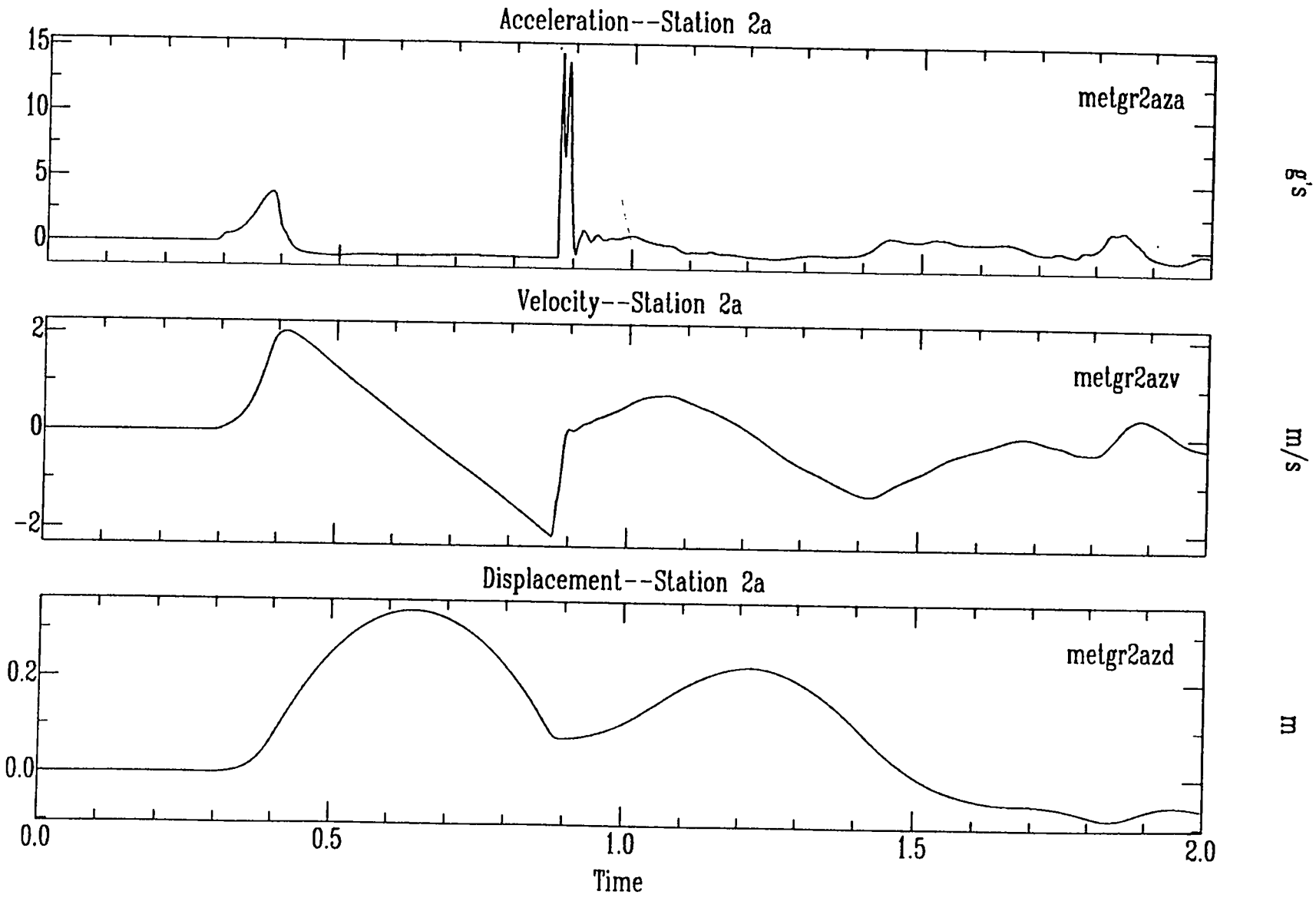
Location	Golf Balls In Dish Dist	Golf Balls In Dish Azi	Golf Balls Out Dist	Golf Balls Out Azi	Steel Balls Red Dist	Steel Balls Red Azi	Steel Balls White Dist	Steel Balls White Azi	Steel Balls Blue Dist	Steel Balls Blue Azi	Steel Balls Green Dist	Steel Balls Green Azi	Steel Balls Orange Dist	Steel Balls Orange Azi	Comments
7-2	2.5	240			0	0	0	0	14.0	345	0	0	***	***	Ball in dish rolled around some
7-3	0	0	0	0	***	***	0	0	5.1	180	***	***	6.4	30	
7-4	0	0	0	0	***	***	0	0	0	0	0	0	***	***	Array next to road, possibly tampered with
7-5	3.8	215	0	0	5.1	270	2.5	115	7.6	300	2.5	100	8.9	315	
7-6	7.6	275	12.7	55	10.2	160	25.4	325	***	***	3.8	40	25.4	315	Numerous cracks reactivated
7-7	17.8	180	29.2	170	22.9	165	20.3	170	14.0	180	45.7	165	26.7	170	Motion toward sink; Nail lost-origin of white ball estimated
8-1	3.8	175			5.1	150	5.1	75	3.8	50	2.5	225	0	0	
8-2	0	0			0	0	0	0	0	0	2.5	315	5.1	110	
8-3	7.6	210	2.5	5	5.1	35	2.5	130	2.5	75	7.6	330	7.6	95	
8-4	2.5	255	12.7	155	30.5	325	22.9	200	10.2	295	3.8	280	2.5	200	
8-5	33.0	190	10.2	75	16.5	255	5.1	180	12.7	165	6.4	285	8.9	160	Numerous cracks
8-6	35.6	180	22.9	30	8.9	135	17.8	195	12.7	125	14.0	205	12.7	95	Fracture through blue pad
8-7	15.2	60	20.3	185	11.4	130	38.1	75	5.1	255	26.7	95	55.9	100	Cracks close to green ball; numerous cracks heading 345°
9-1	2.5	135			0	0	0	0	0	0	0	0	0	0	
9-2	0	0			2.5	25	0	0	2.5	205	0	0	0	0	
9-3	5.1	290	0	0	0	0	0	0	0	0	0	0	0	0	
9-6	15.2	180	30.5	75	14.0	195	2.5	170	17.8	105	22.9	75	39.4	75	
9-7	10.2	25	17.8	265	8.9	0	7.6	65	26.7	35	15.2	75	14.0	60	Crack close to orange ball heading 345°
9-8	27.9	315	58.4	70	38.1	85	26.7	95	30.5	90	53.3	65	25.4	65	Ground slightly disrupted

Table 11. Metropolis SIG Results (Concluded)

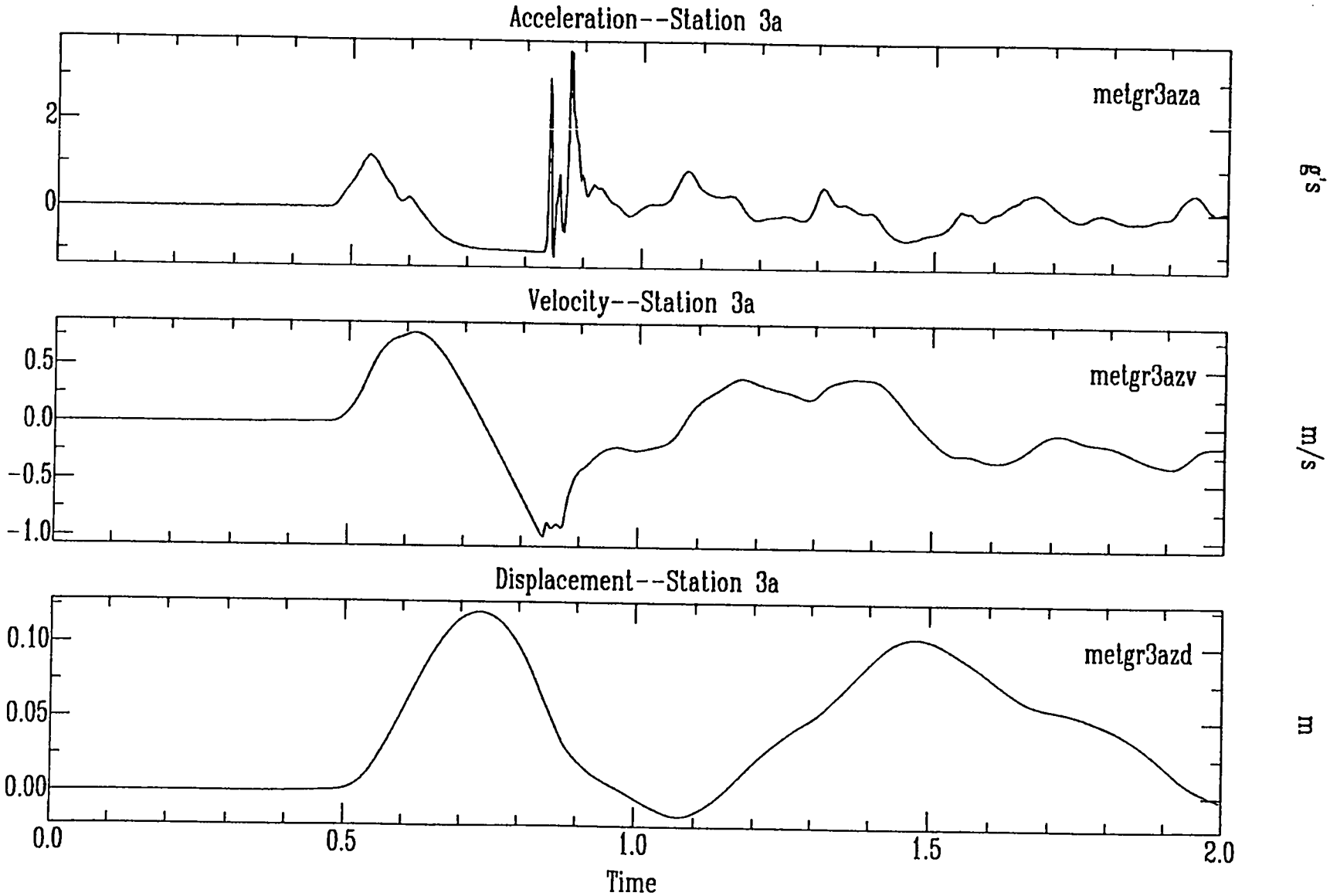
Location	Golf Balls In Dish Dist	Golf Balls In Dish Azi	Golf Balls Out Dist	Golf Balls Out Azi	Steel Balls Red Dist	Steel Balls Red Azi	Steel Balls White Dist	Steel Balls White Azi	Steel Balls Blue Dist	Steel Balls Blue Azi	Steel Balls Green Dist	Steel Balls Green Azi	Steel Balls Orange Dist	Steel Balls Orange Azi	Comments
10-1	30	0			0	0	0	0	0	0	0	0	0	0	
10-2	0	0			11.4	325	2.5	355	5.1	205	2.5	55	0	0	
10-3	5.1	280	10.2	190	6.4	190	2.5	275	12.7	260	6.4	215	0	0	Minor reactivation of Yucca Fault
10-4	5.1	210	15.2	105	10.2	180	0	0	3.8	255	0	0	15.2	215	
10-5	35.1	290	15.2	230	16.5	255	0	0	0	0	12.7	270	14.0	15	
10-6	2.5	180	20.3	100	0	0	3.8	215	11.4	245	3.8	265	6.4	215	
10-7	22.9	195	43.2	145	15.2	135	30.5	145	7.6	45	3.8	215	2.5	280	
11-5	3.8	135	25.4	250	10.2	285	14.0	50	2.5	305	22.9	60	16.5	125	
11-6	30.5	325	55.9	195	53.3	215	15.2	300	55.9	60	213.4	120	27.9	220	Disruption zone around Yucca Fault; nail lost, origin of green ball estimated
11-7	41.9	215	15.2	60	10.2	350	12.7	70	24.1	220	5.1	295	10.2	185	Green pad covered with rocks, surface slightly disrupted
11-8	55.9	195	30.5	60	43.2	95	40.6	75	3.8	345	12.7	55	30.5	75	
12-2	5.1	255	8.9	300	0	0	0	0	0	0	3.8	35	0	0	
12-3	0	0	20.3	350	15.2	150	5.1	215	11.4	60	7.6	25	0	0	White ball found in a depression
12-4	2.5	15	1.3	115	5.1	140	0	0	0	0	0	0	0	0	Ball rolled around in dish
12-5	22.9	165	17.8	100	20.3	120	29.2	105	15.2	100	25.4	120	6.3	115	
12-6	83.8	165	43.2	125	7.6	150	19.1	95	40.6	110	36.8	145	39.4	150	

Distance moved (Dist) in centimeters; azimuth moved (Azi) in degrees from true north.
*** Ball was found to be missing postshot.

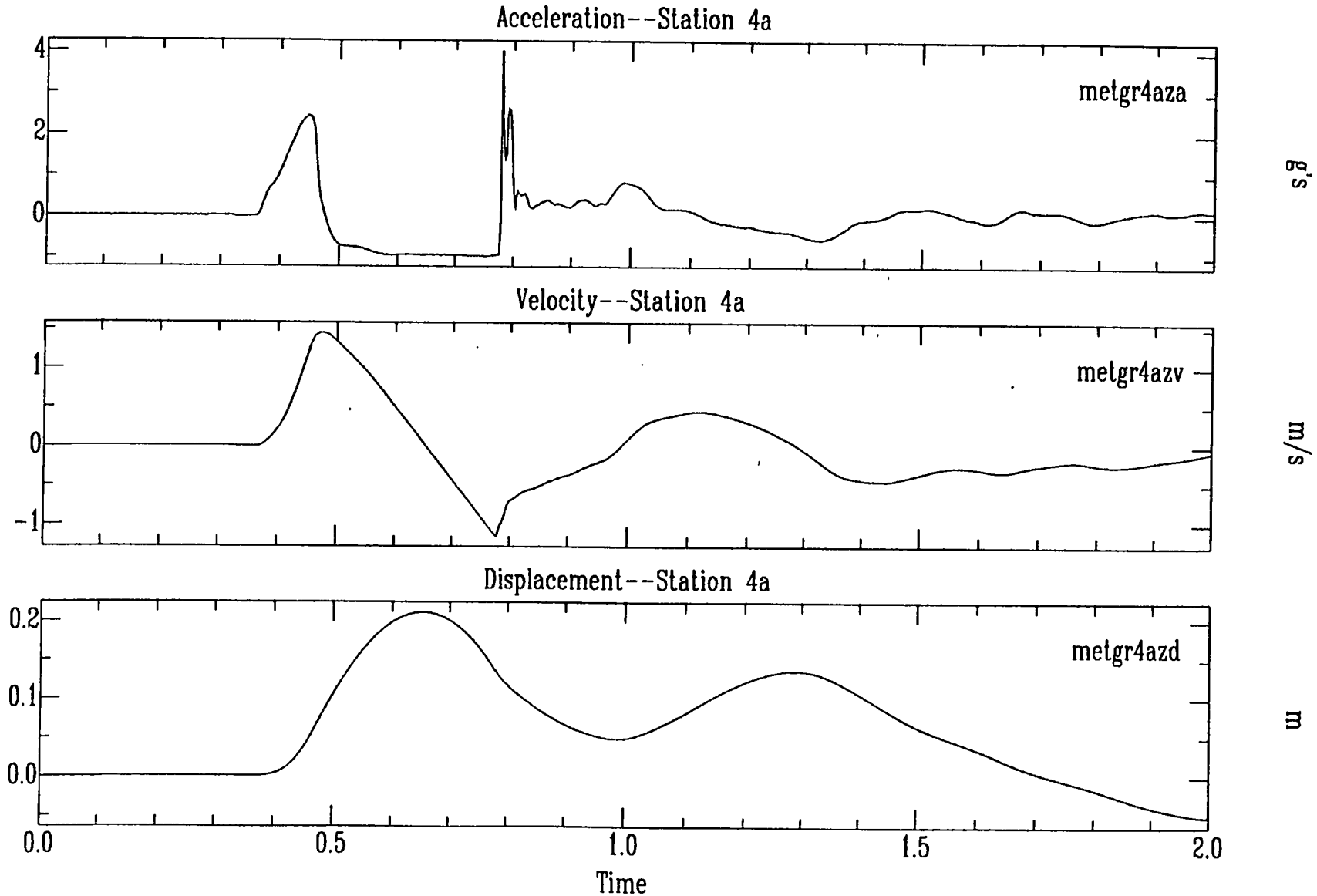
Metropolis Surface Ground Motion



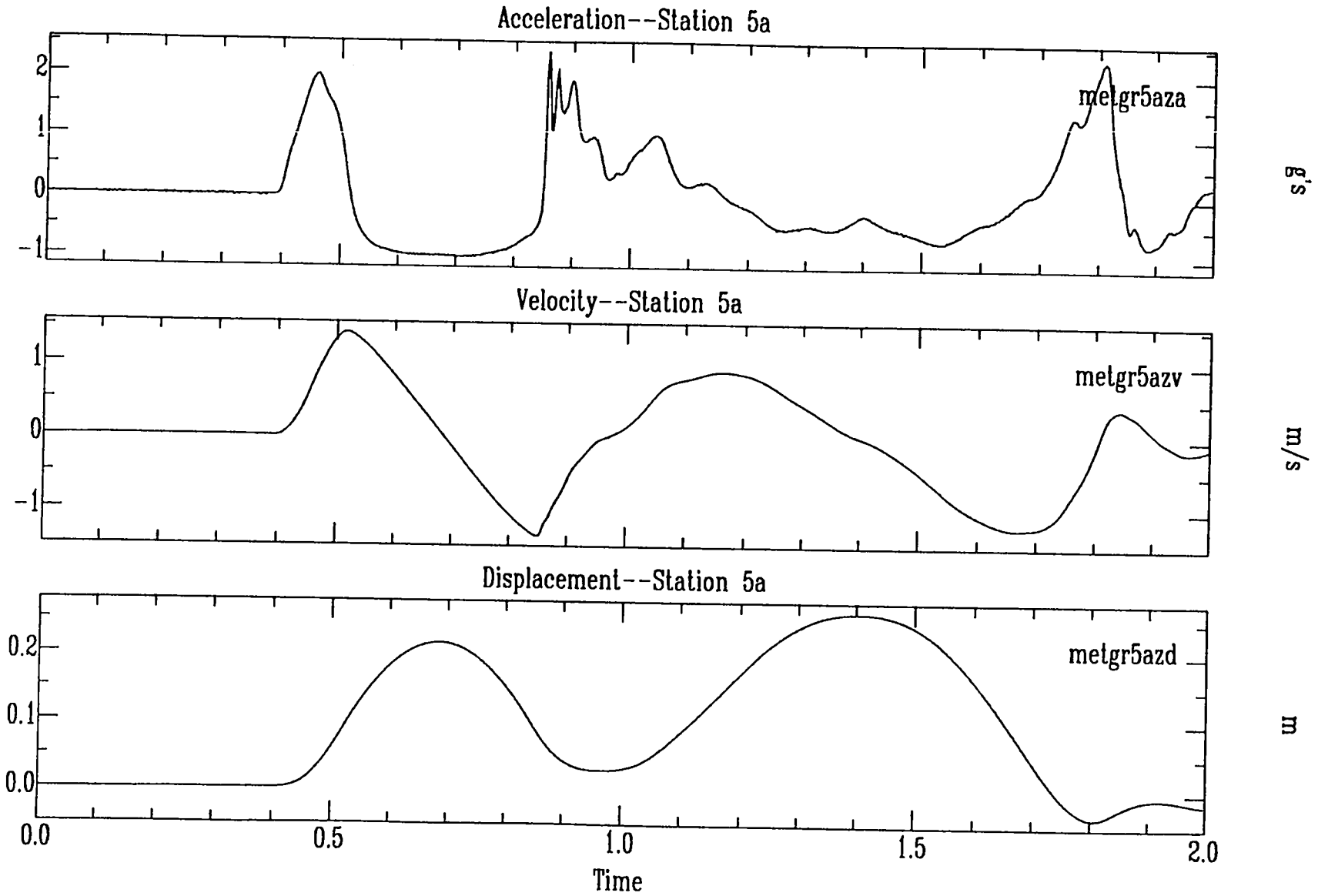
Metropolis Surface Ground Motion



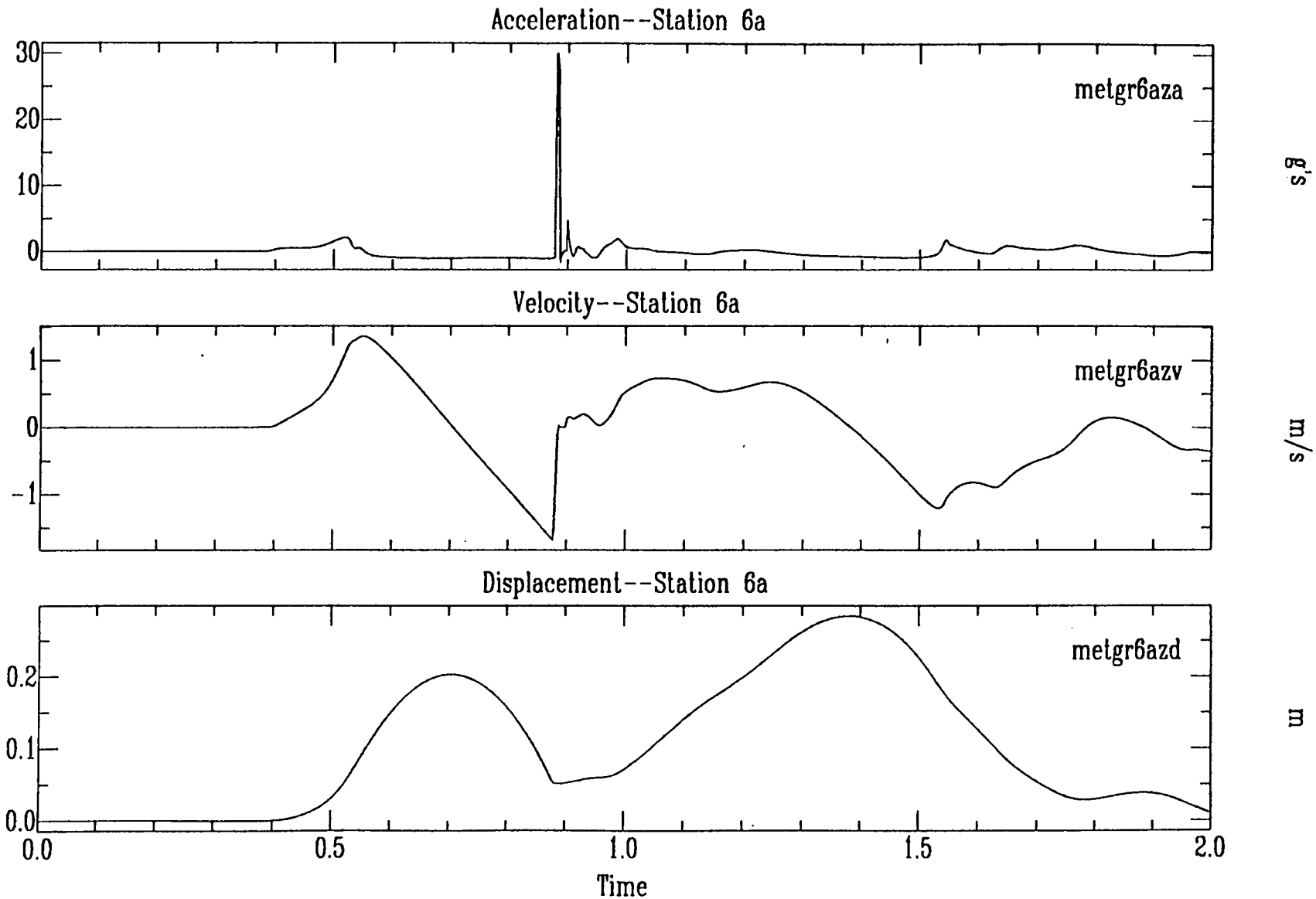
Metropolis Surface Ground Motion



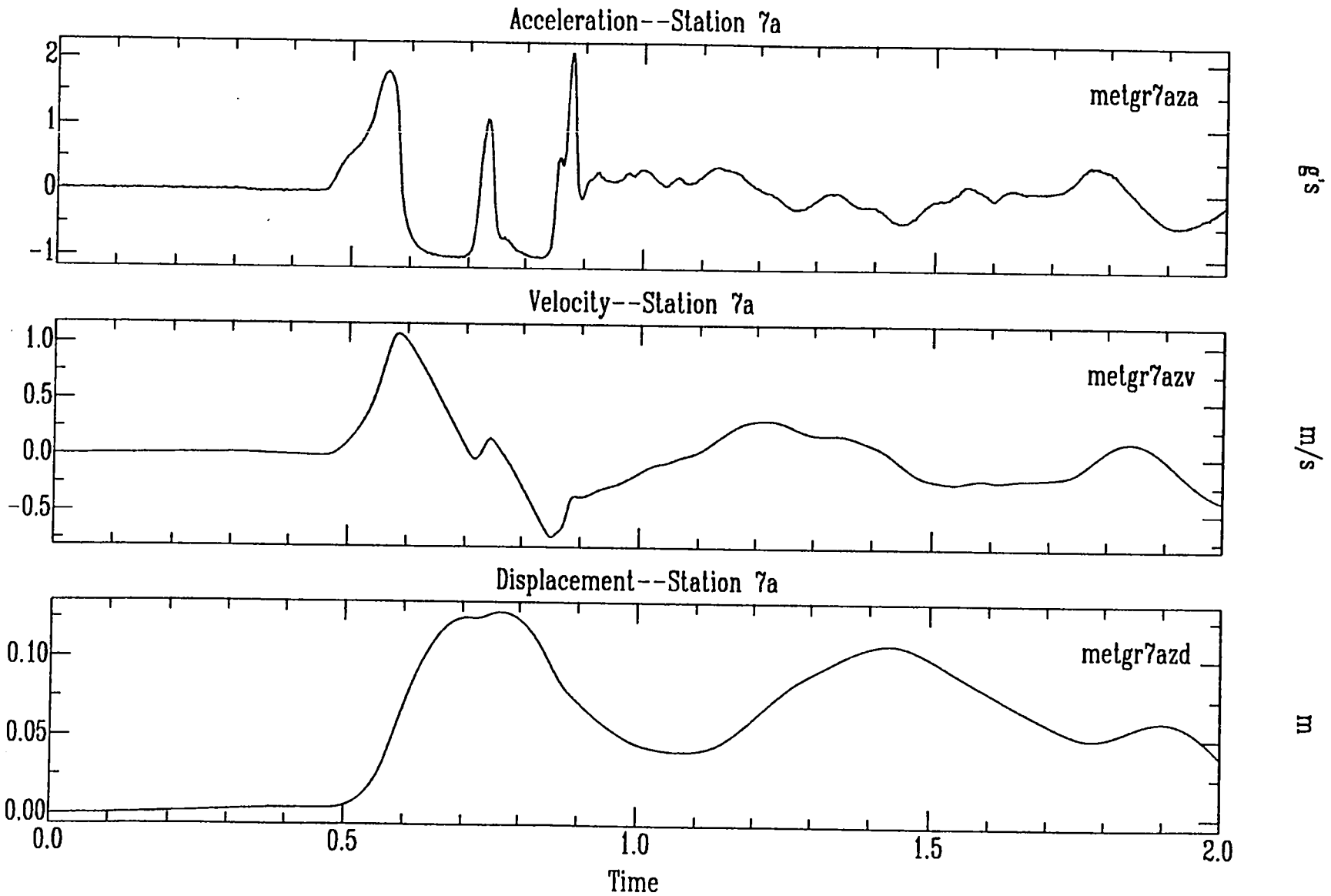
Metropolis Surface Ground Motion



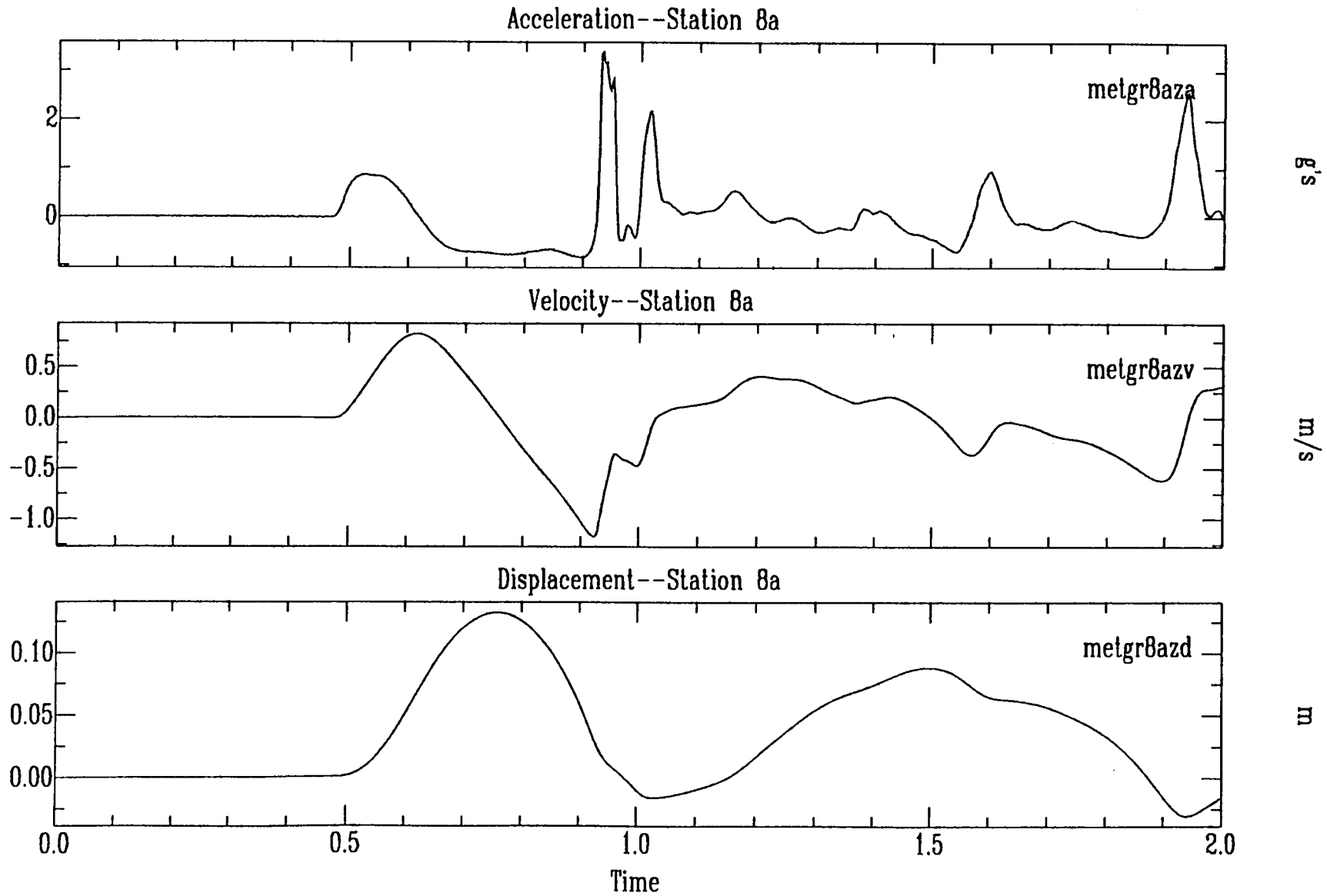
Metropolis Surface Ground Motion



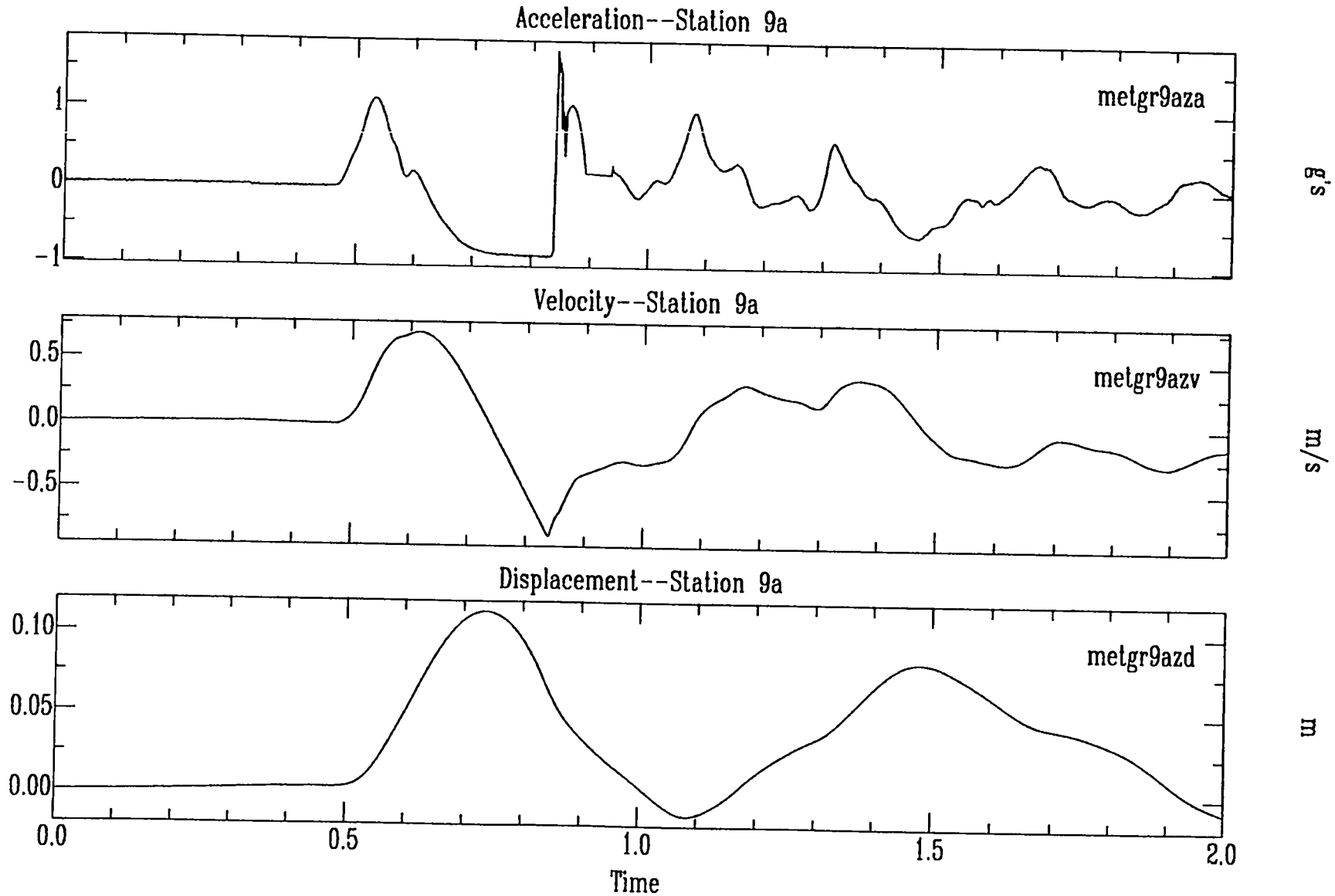
Metropolis Surface Ground Motion



Metropolis Surface Ground Motion



Metropolis Surface Ground Motion



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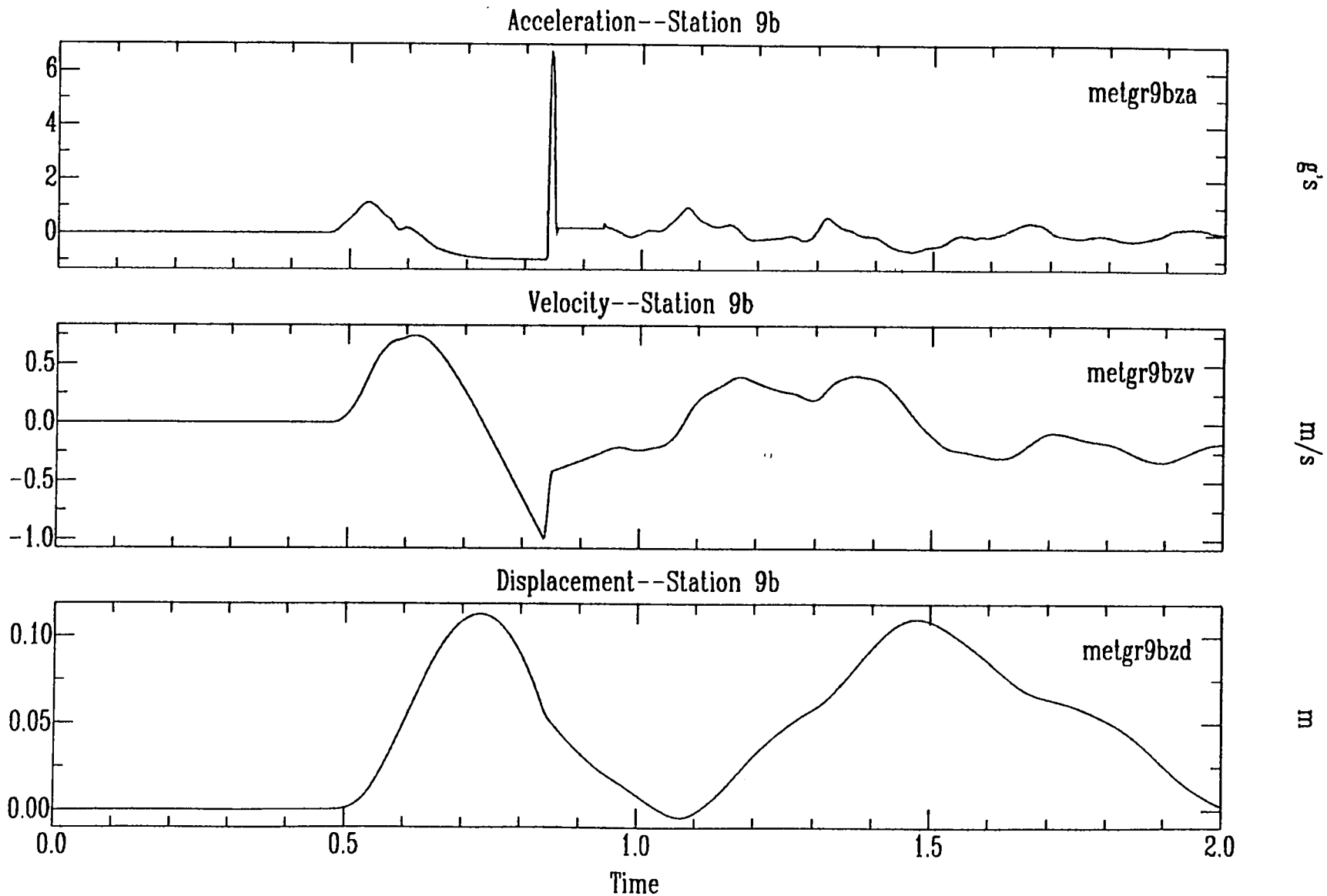

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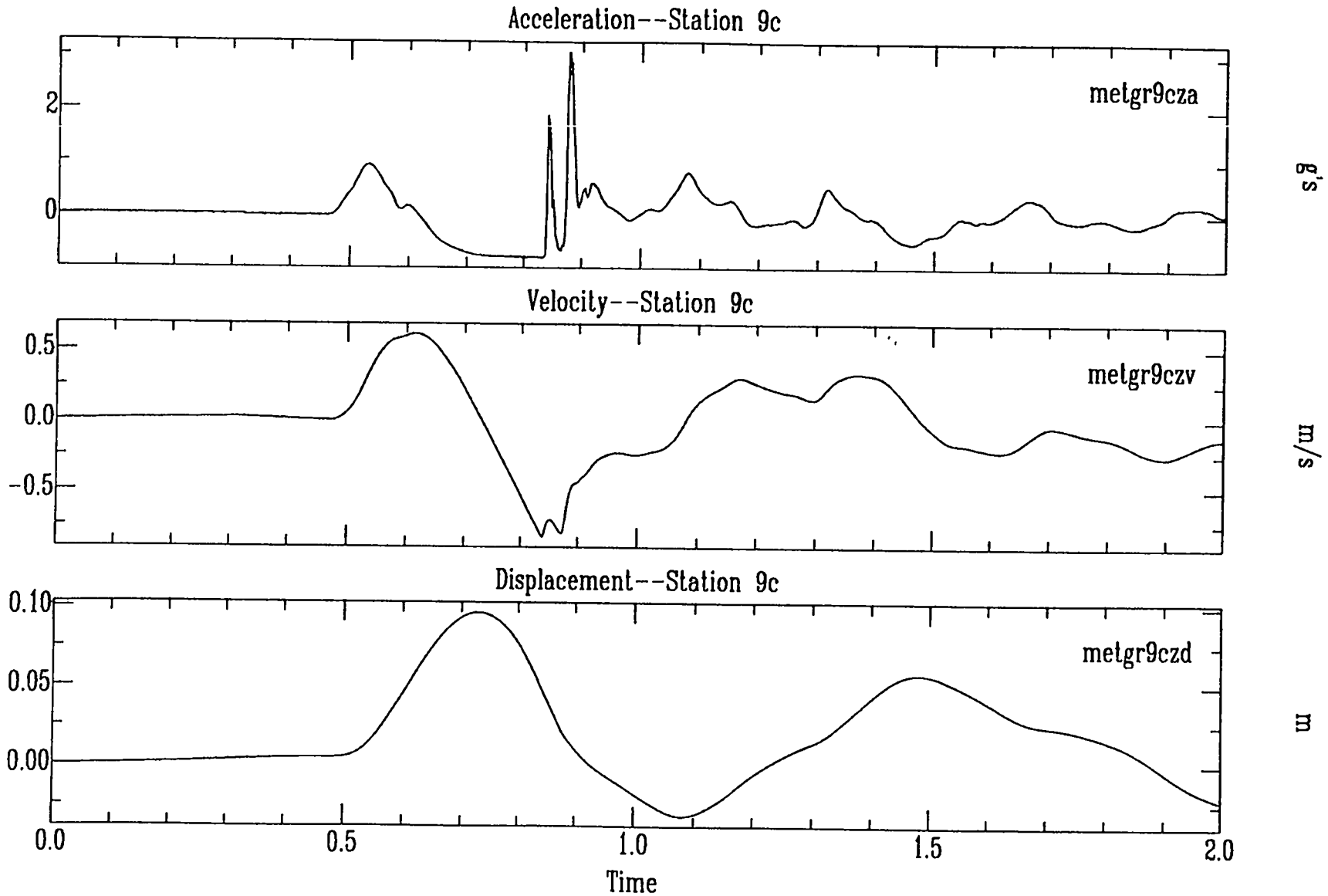

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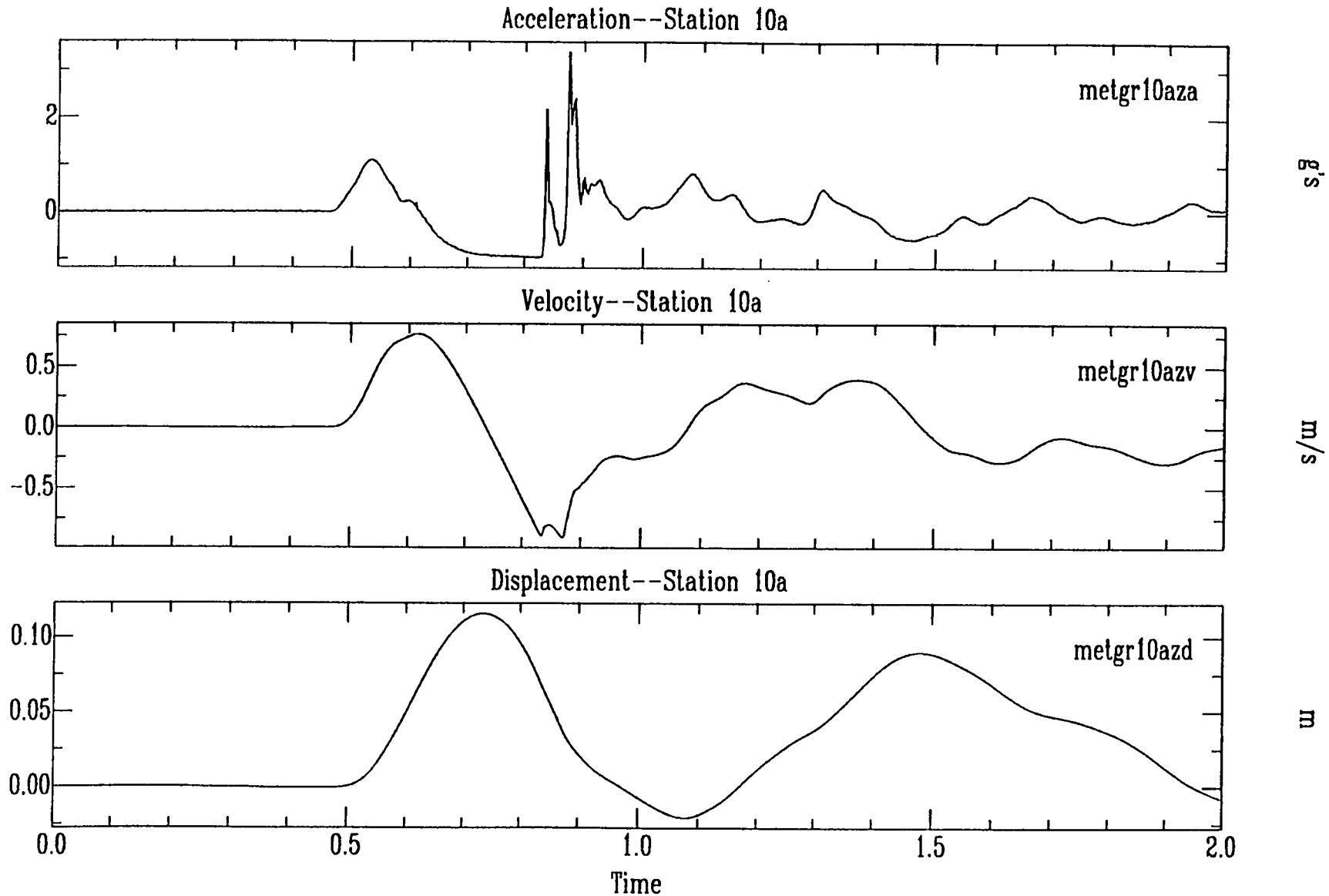

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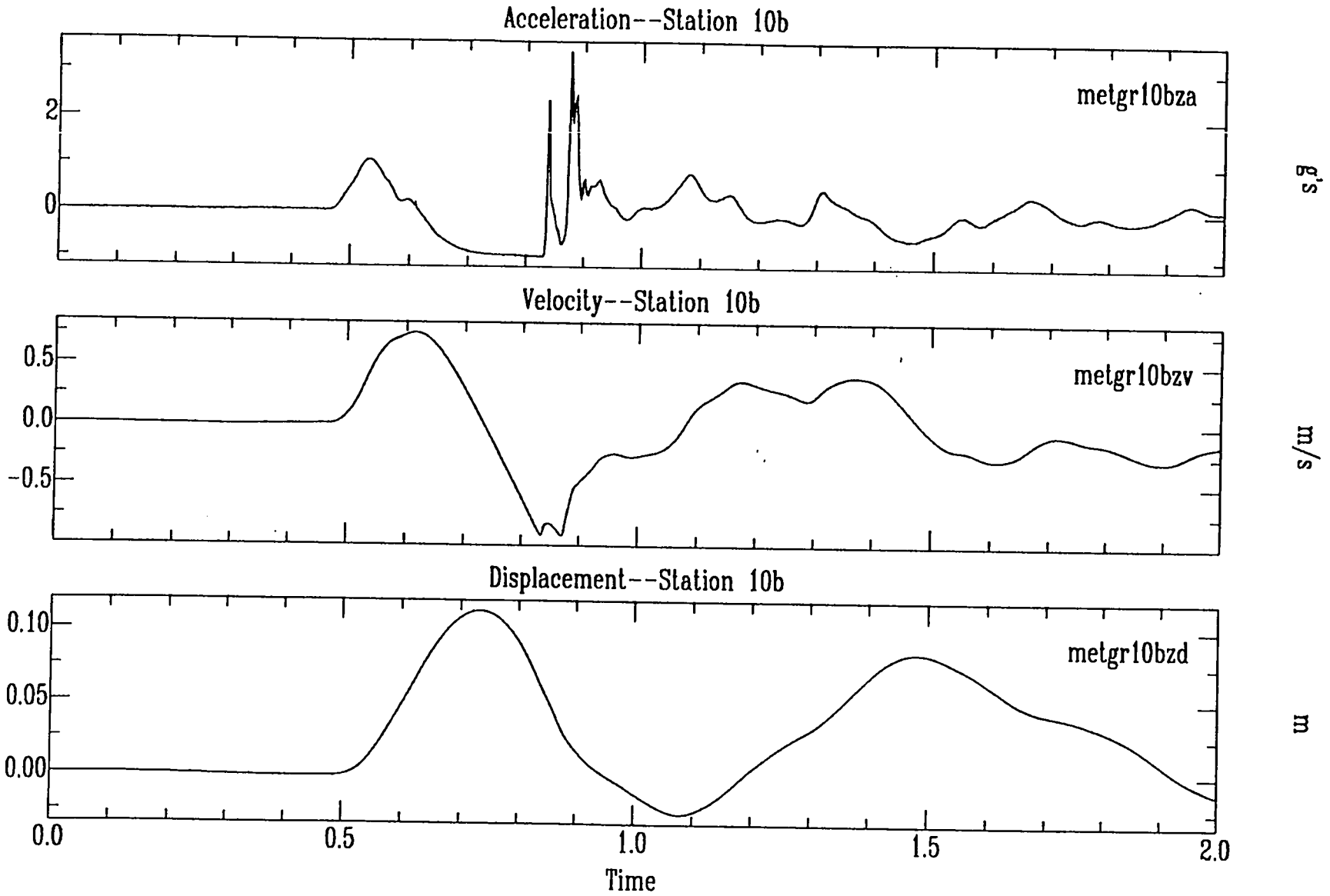

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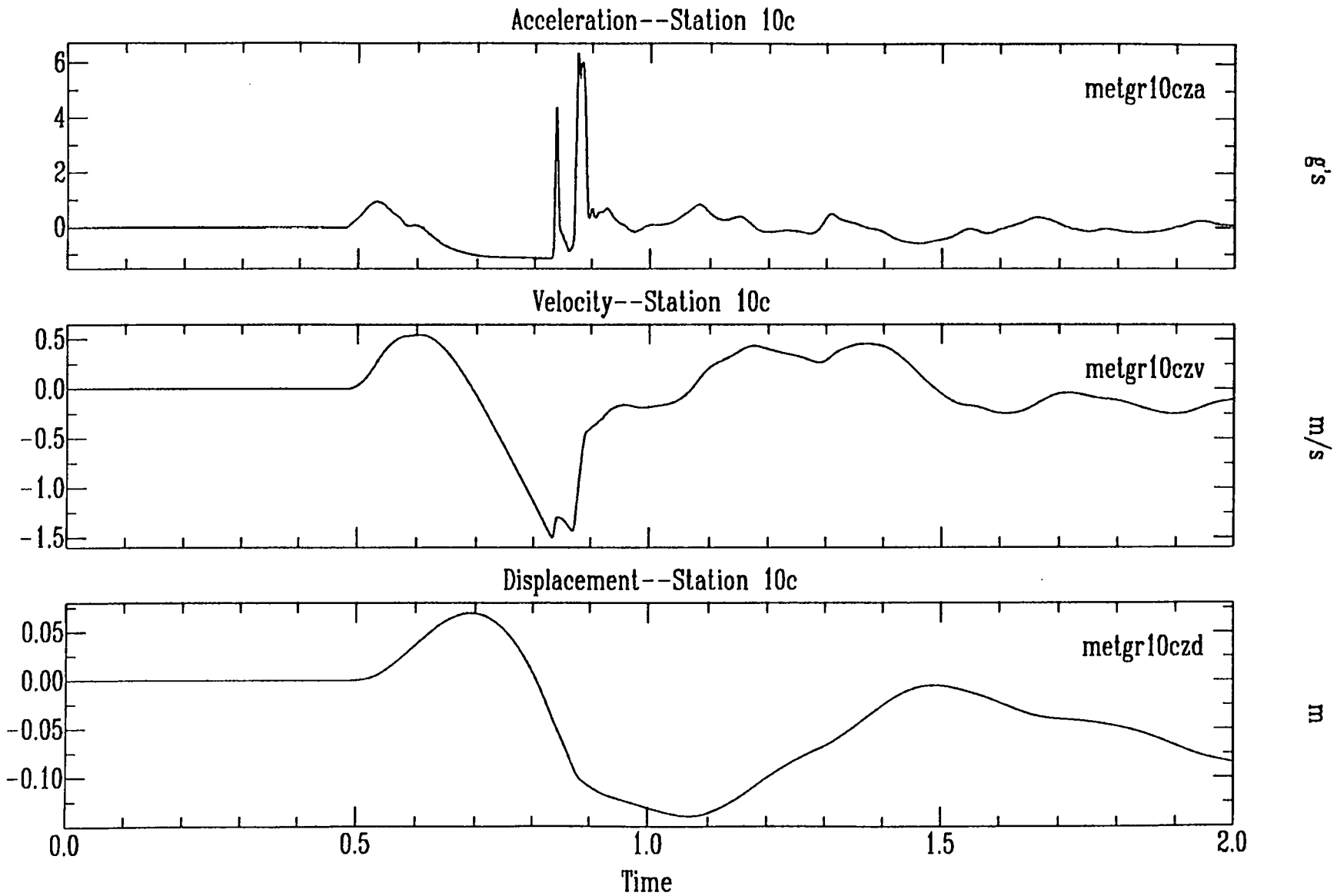

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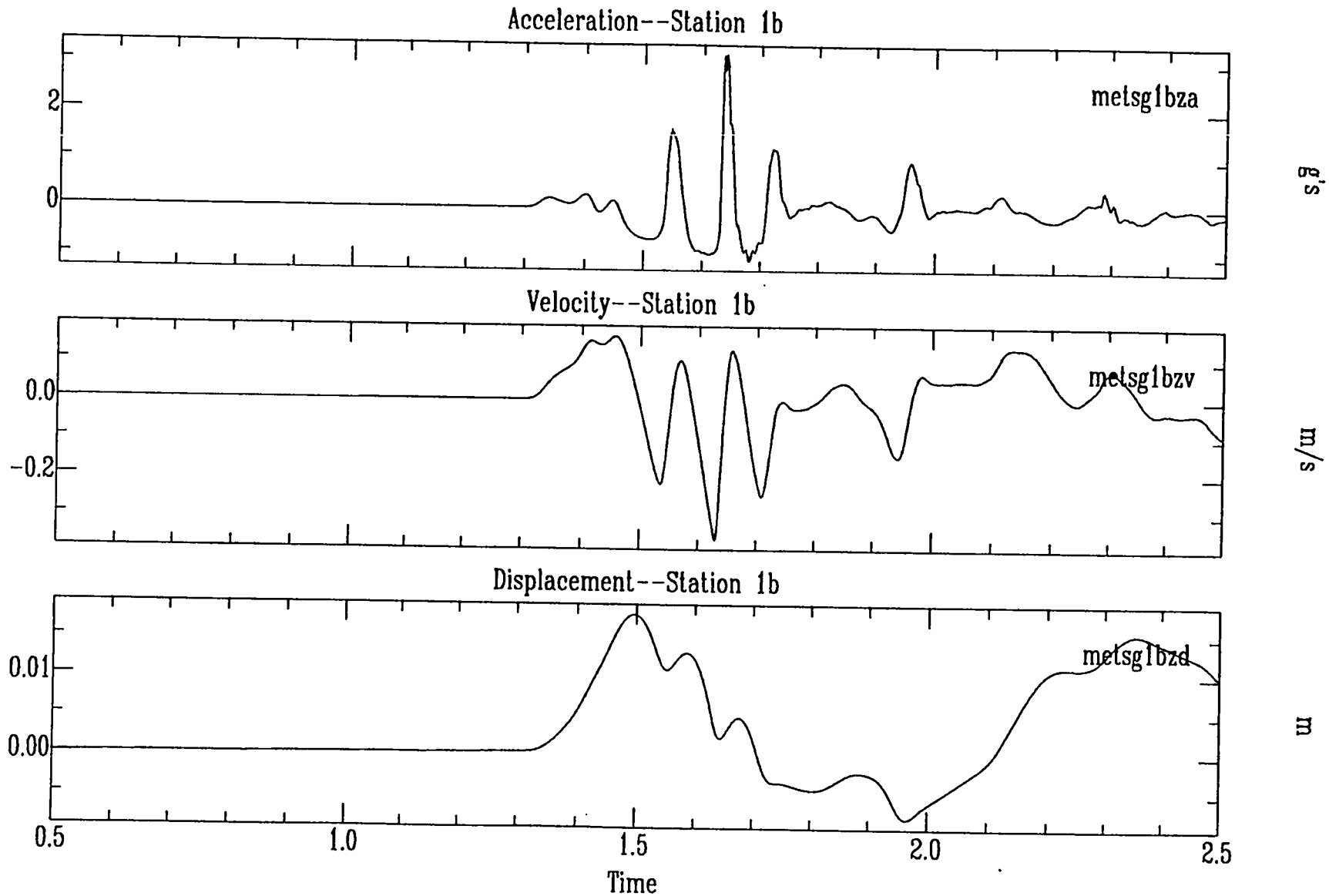

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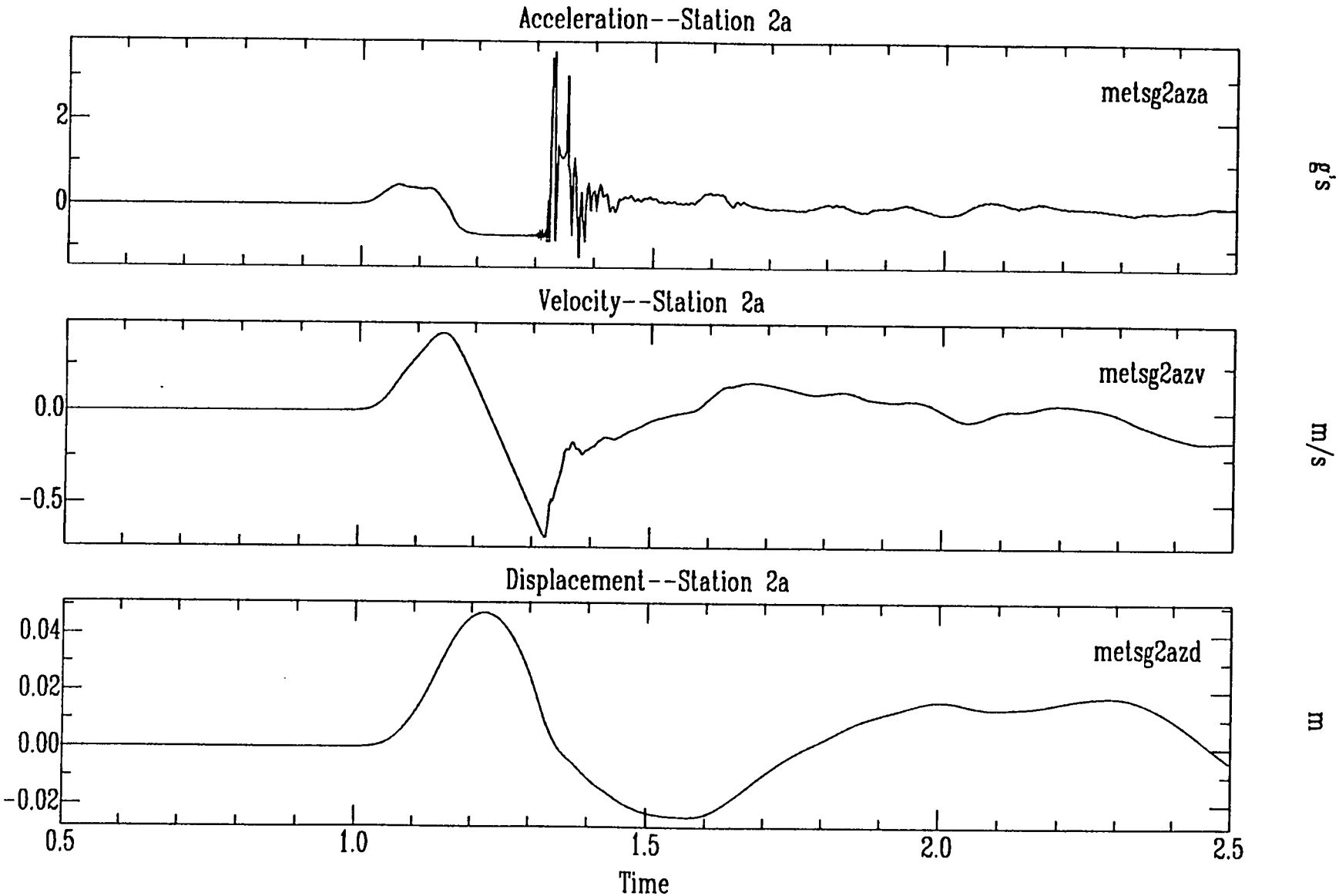

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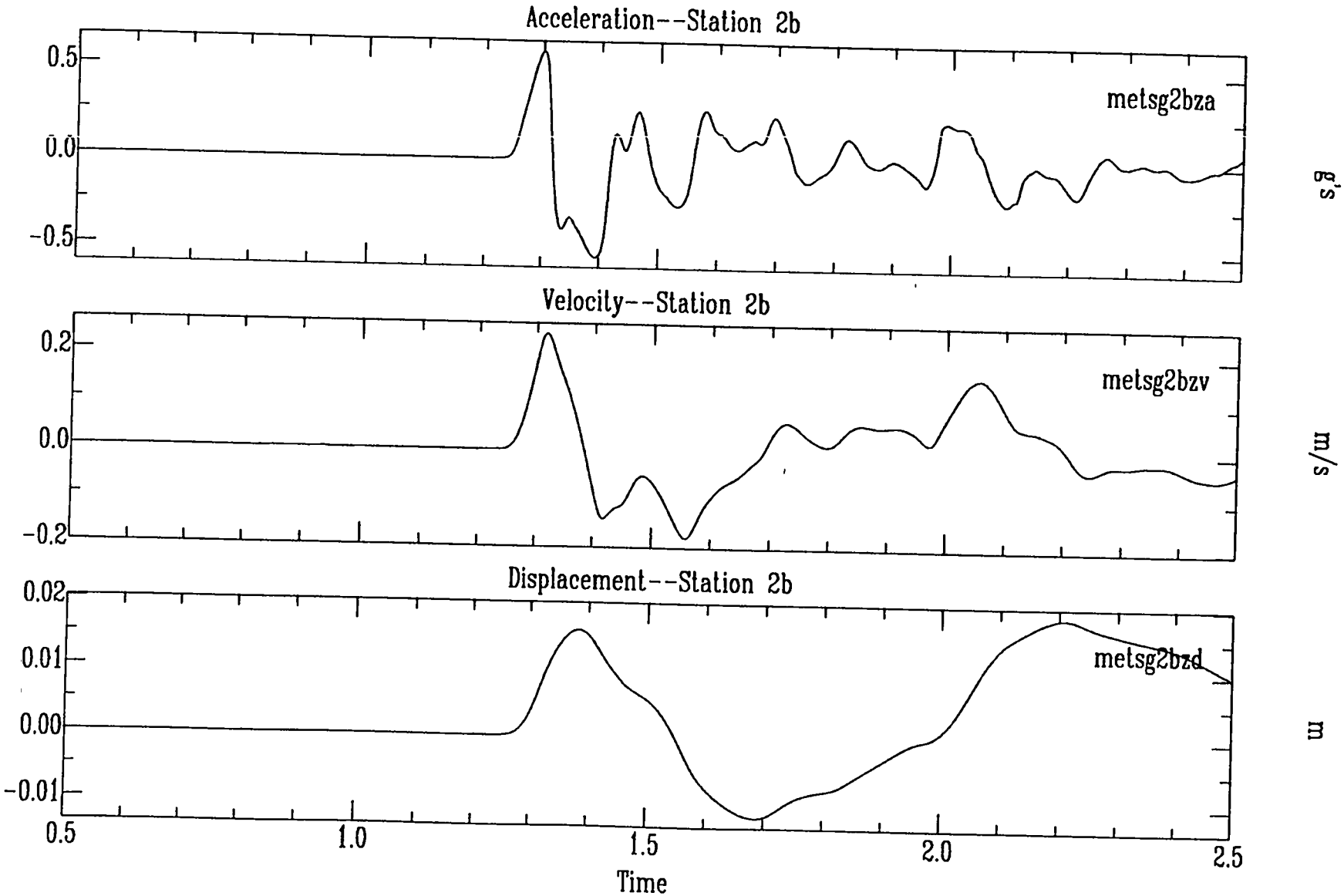

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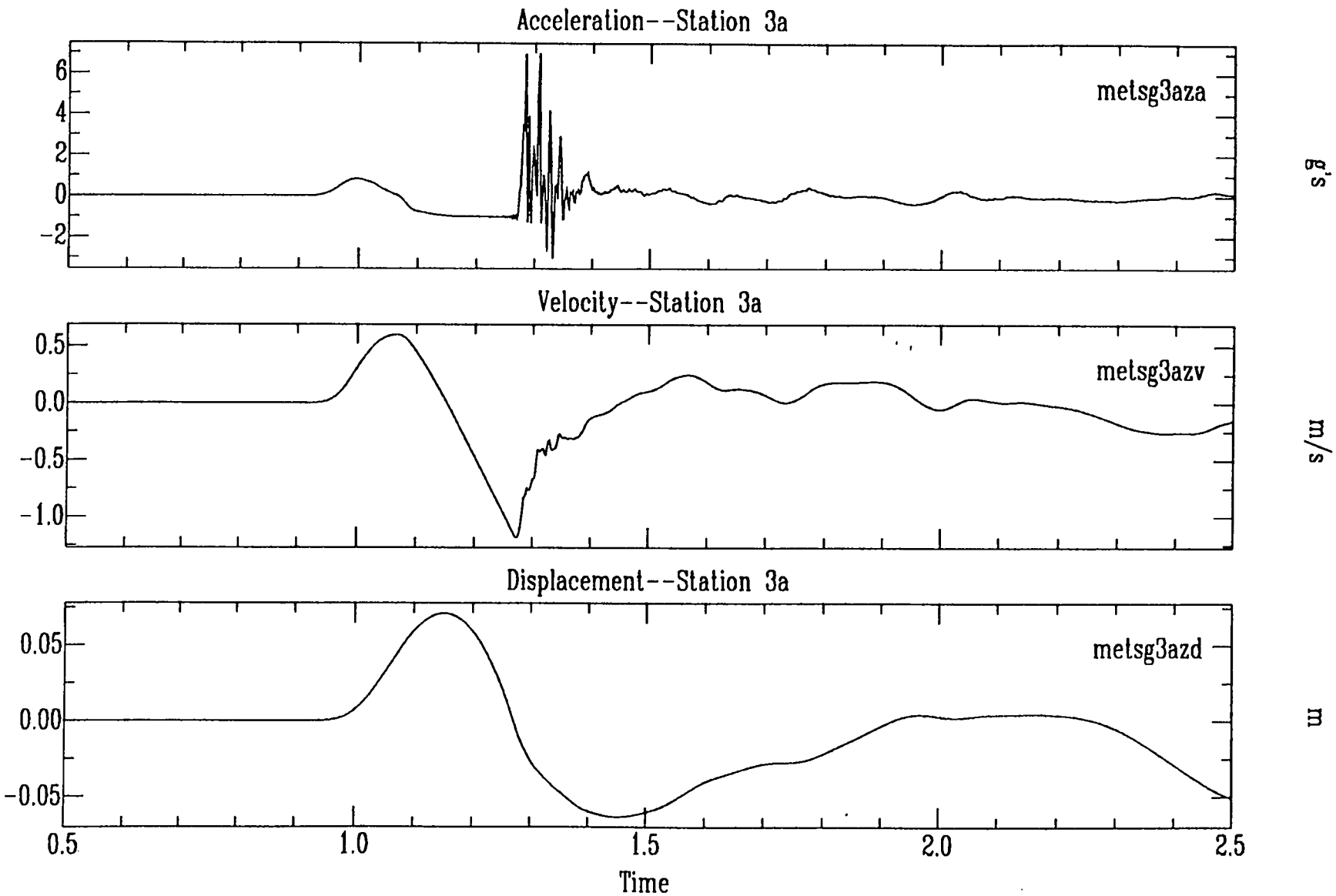

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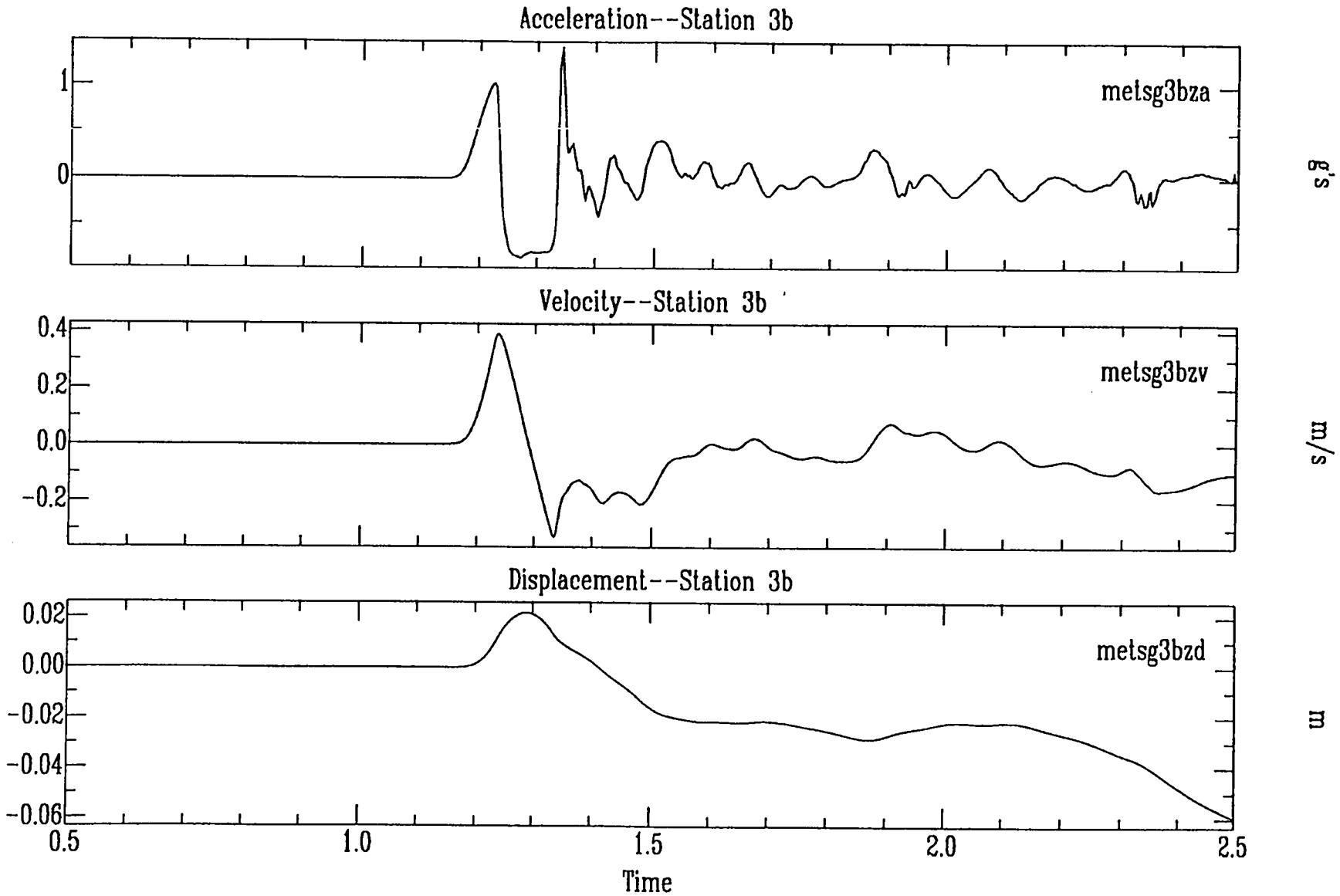

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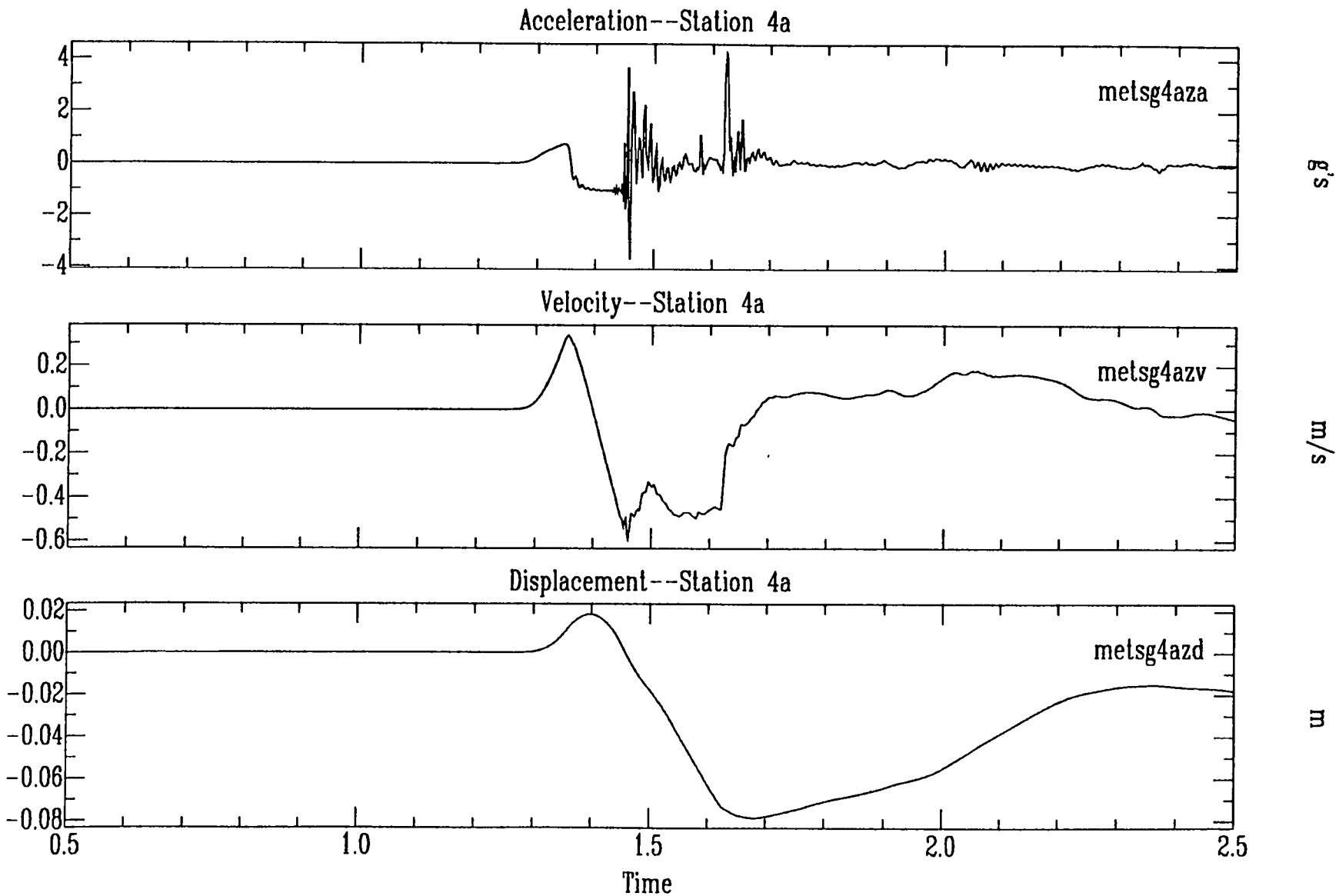

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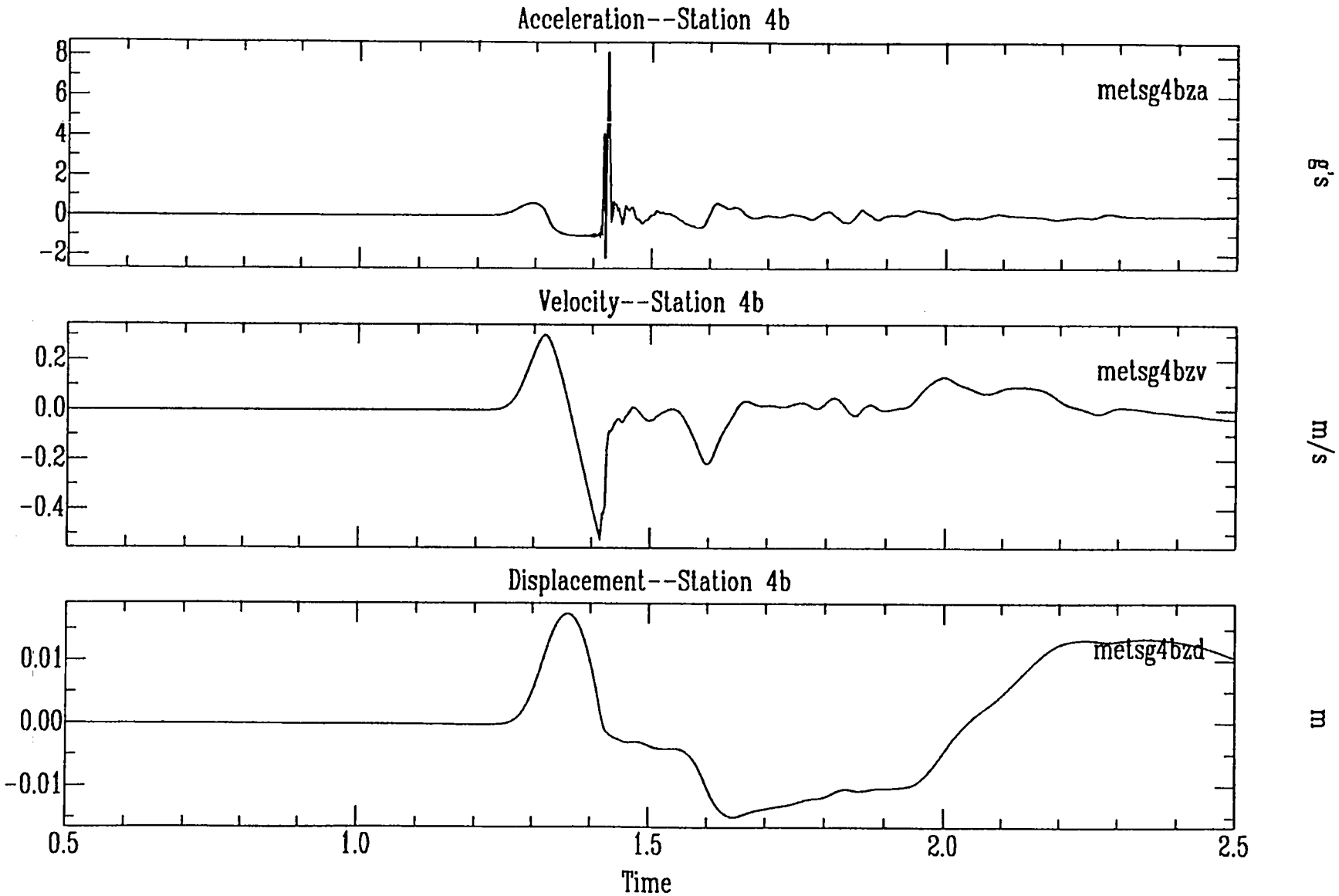

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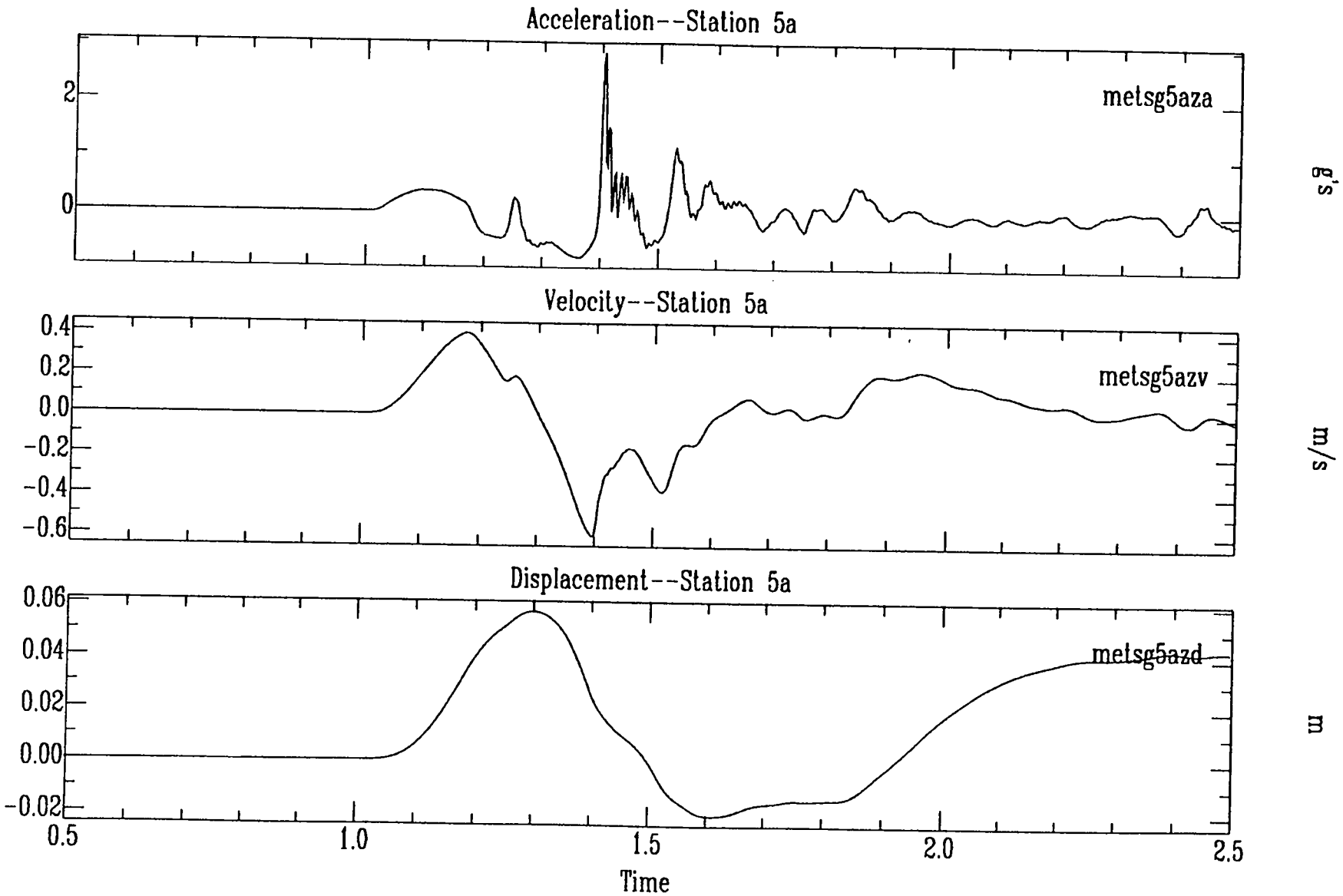

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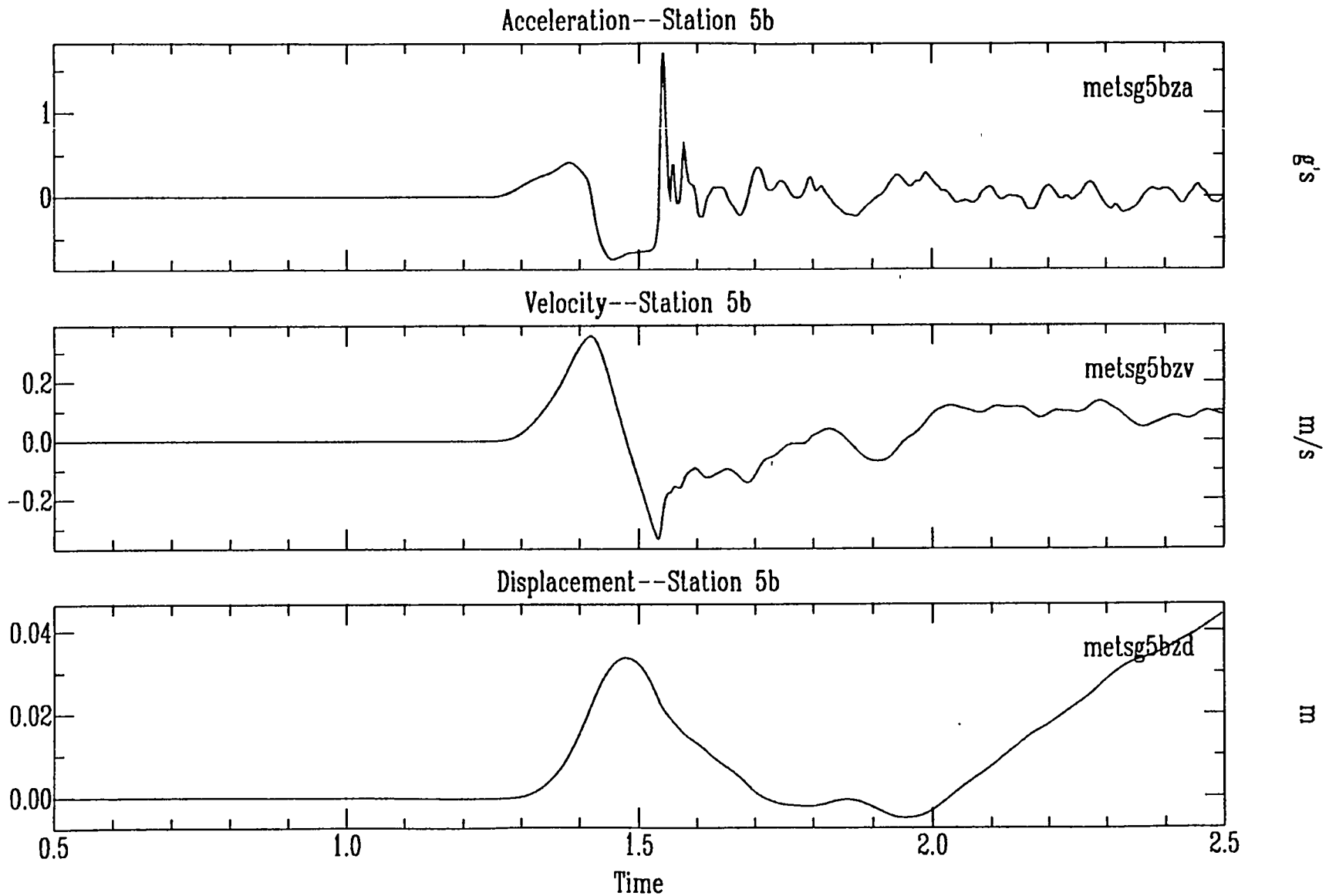

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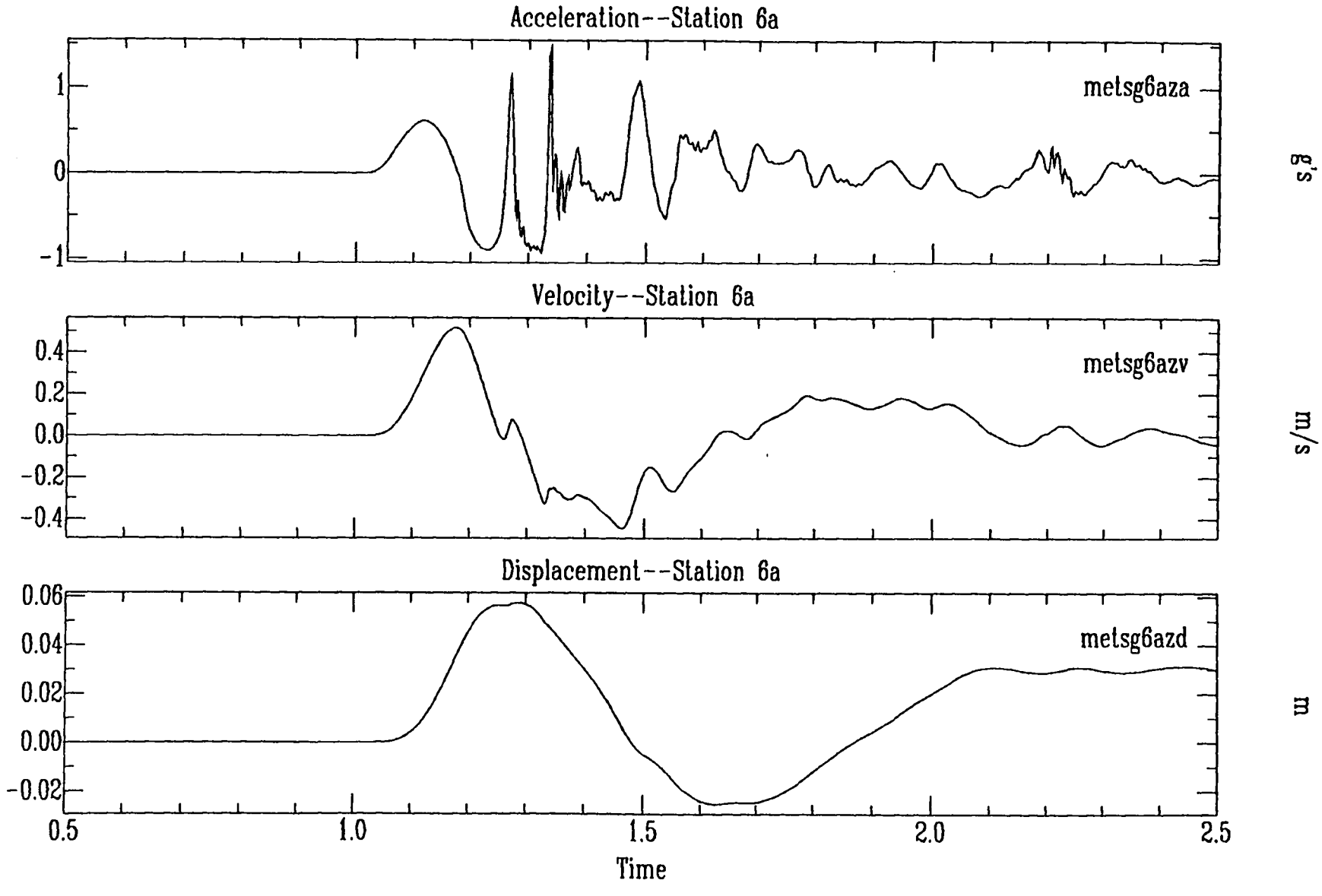

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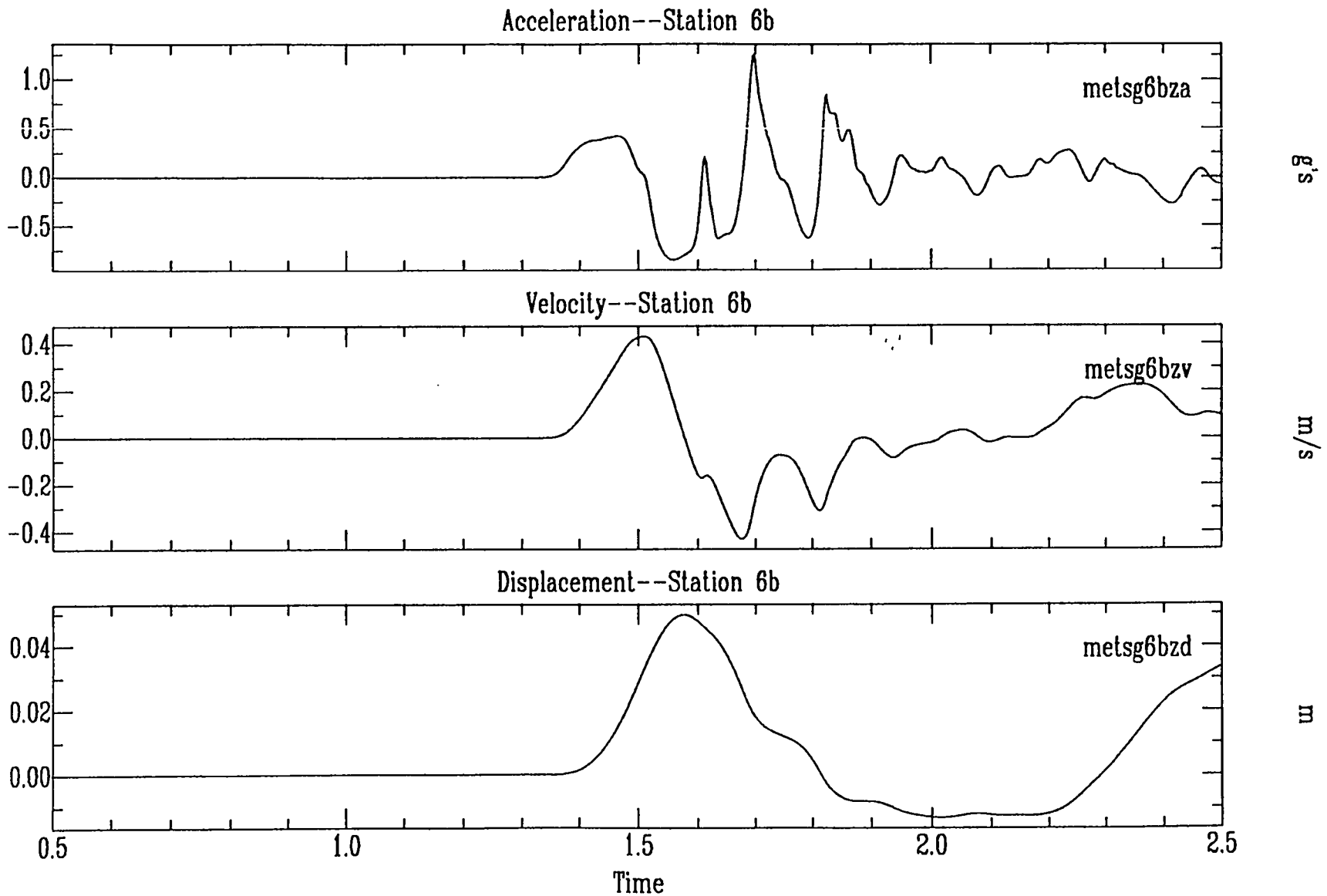

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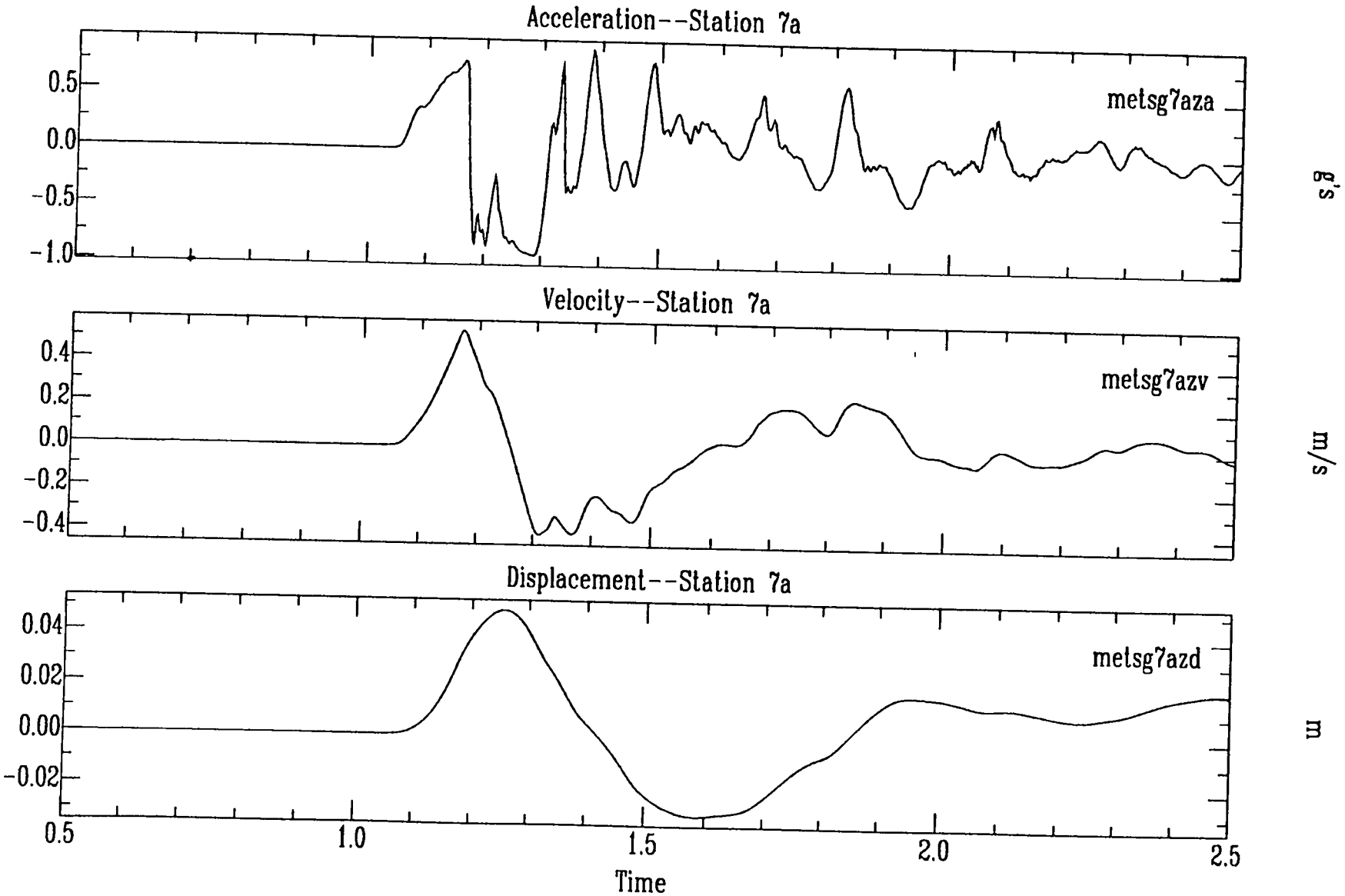

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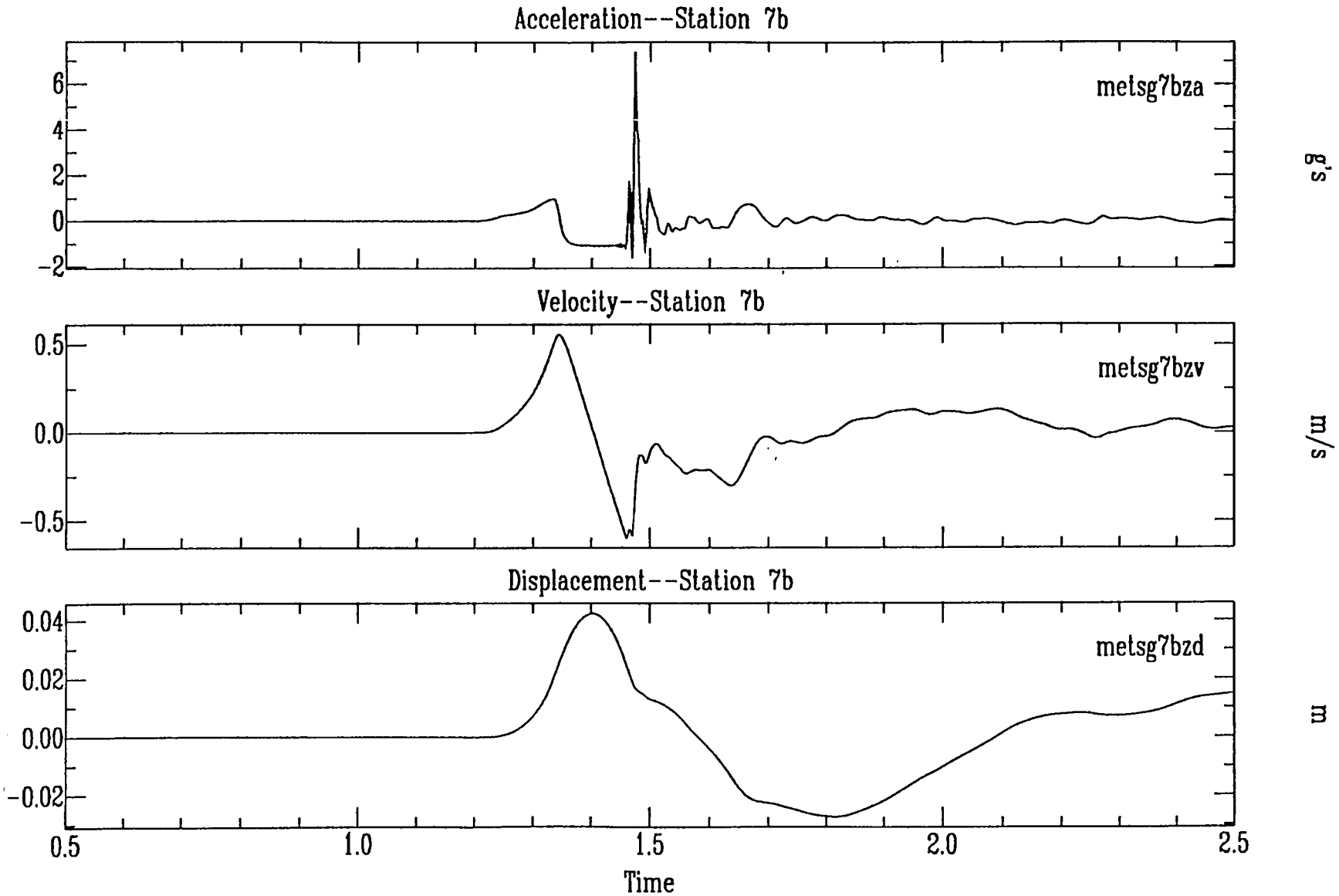

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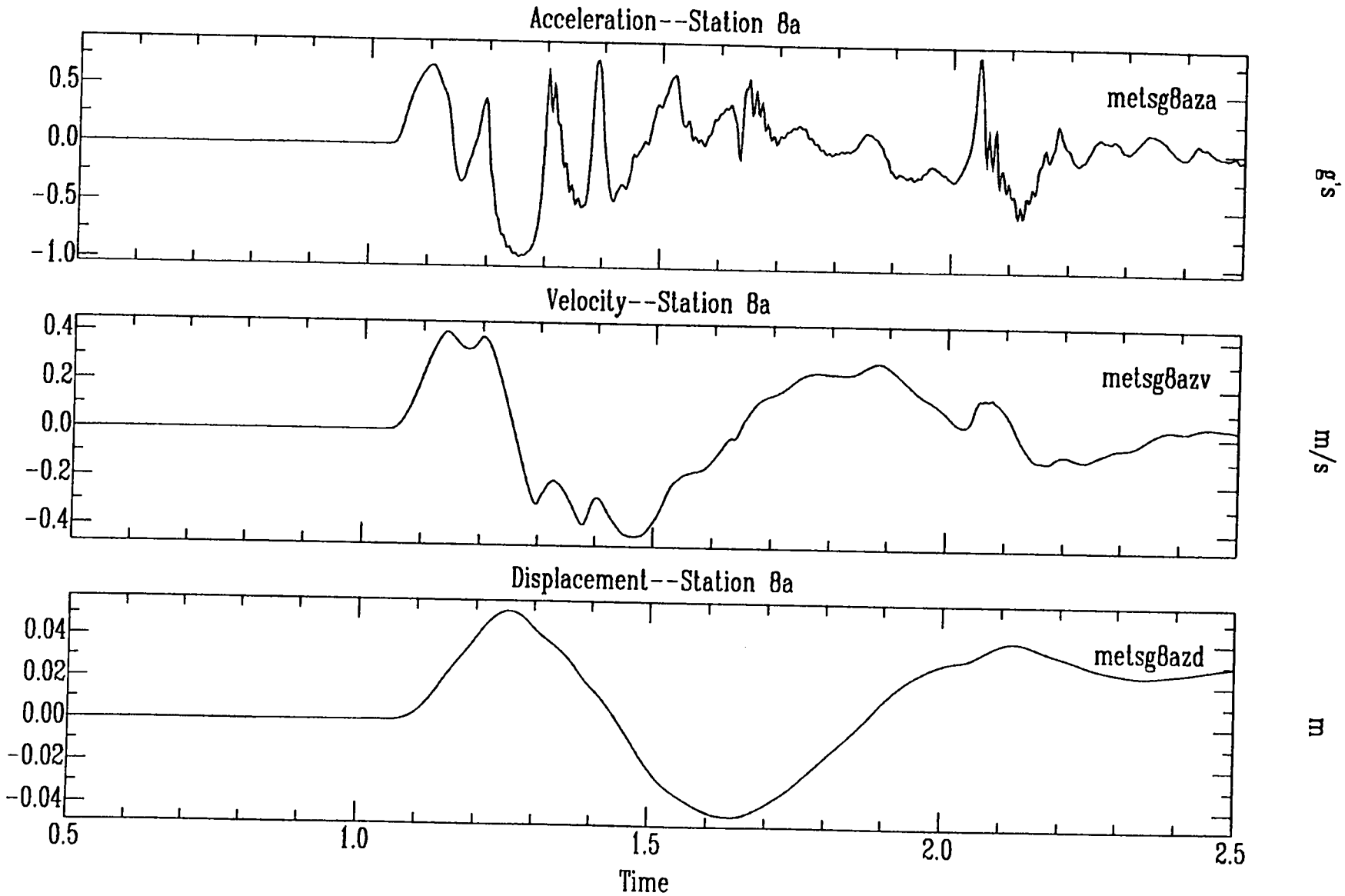

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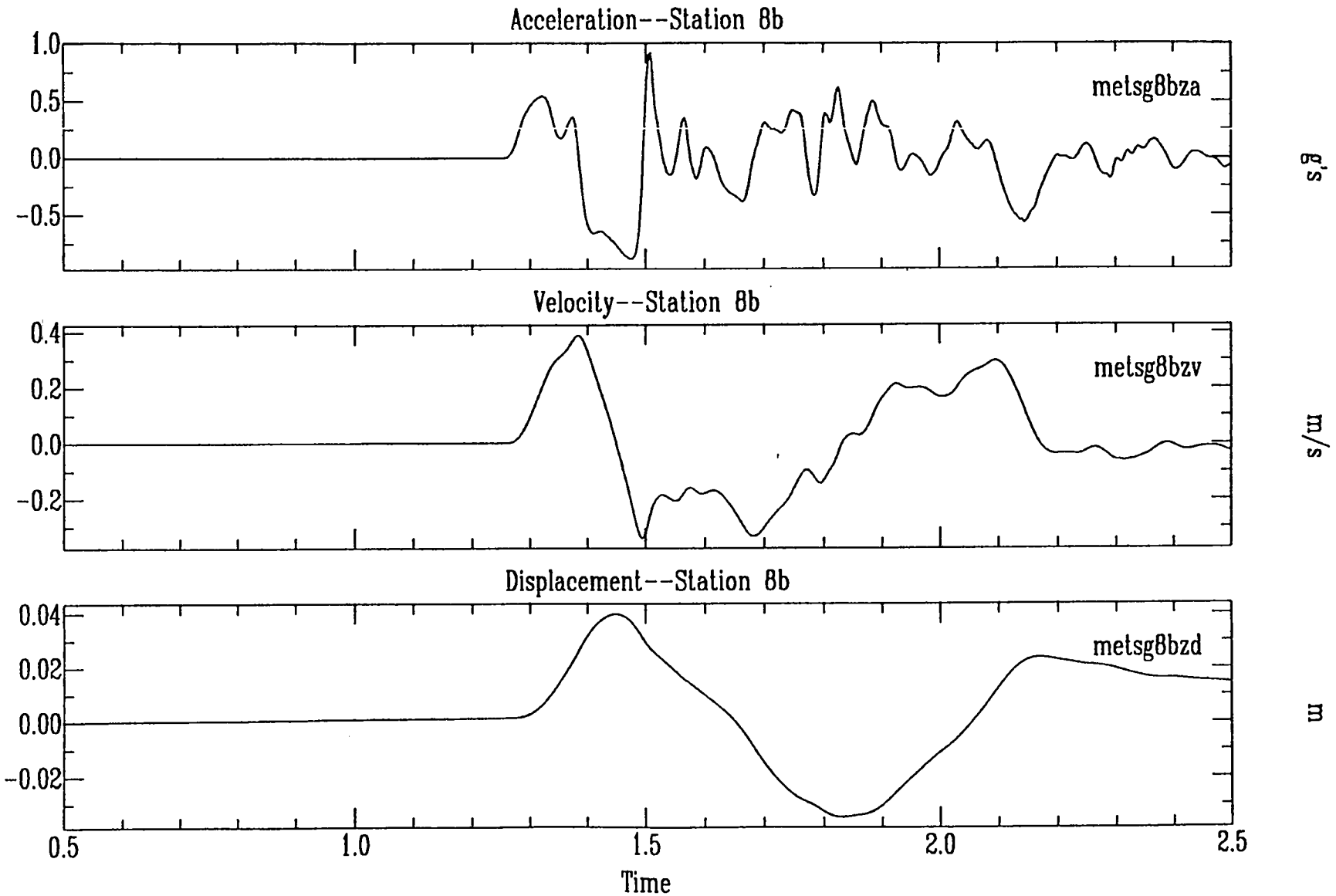

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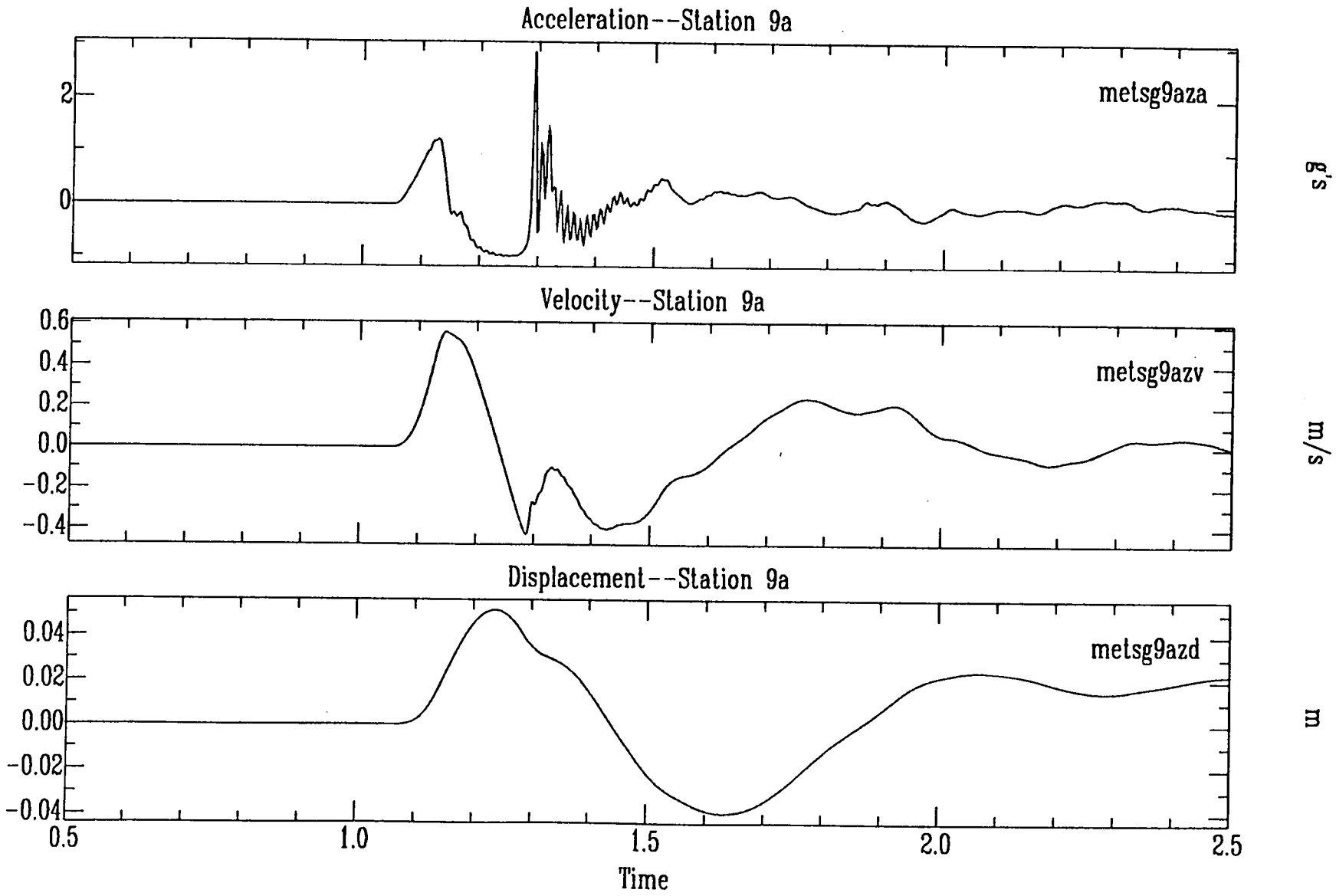

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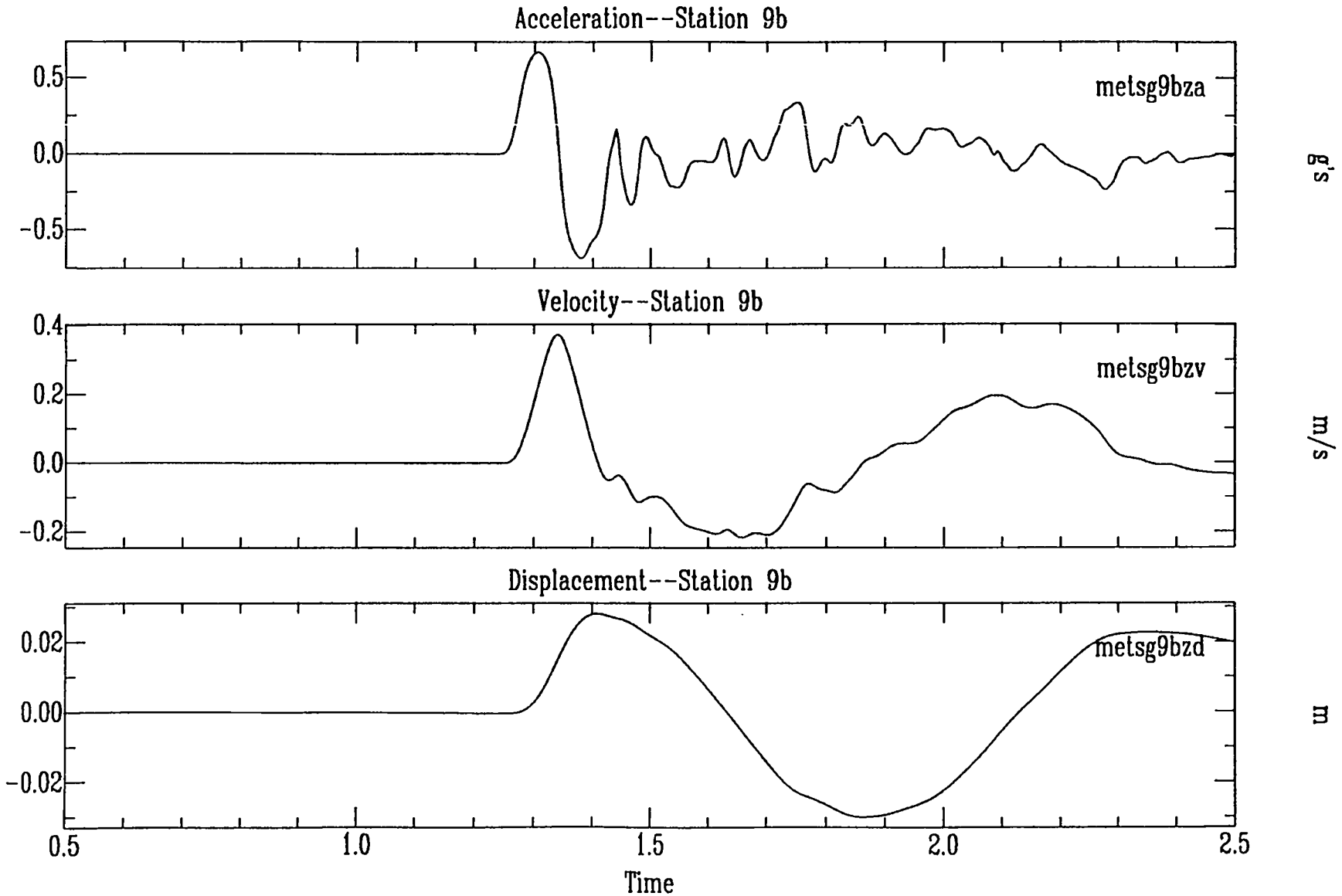

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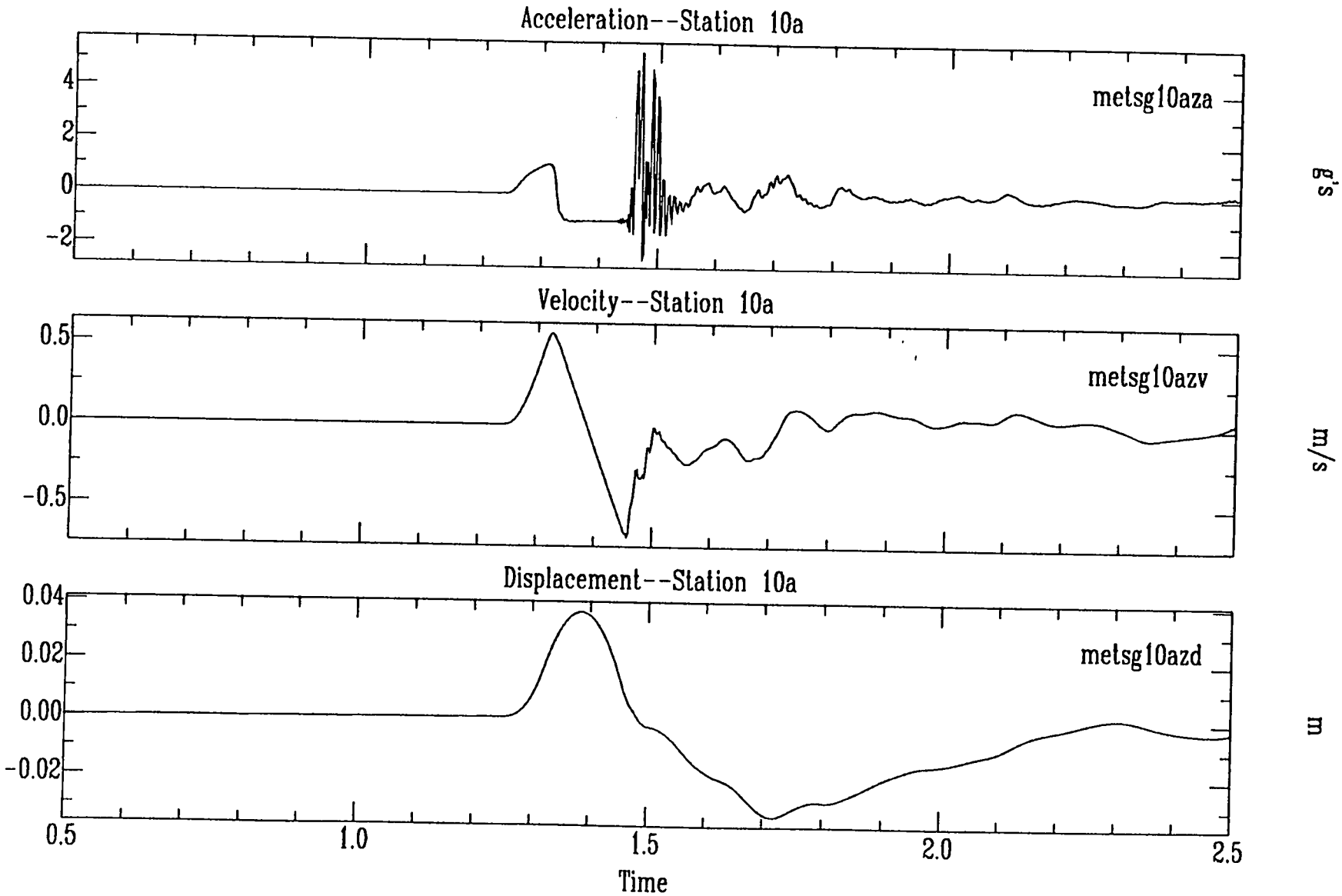

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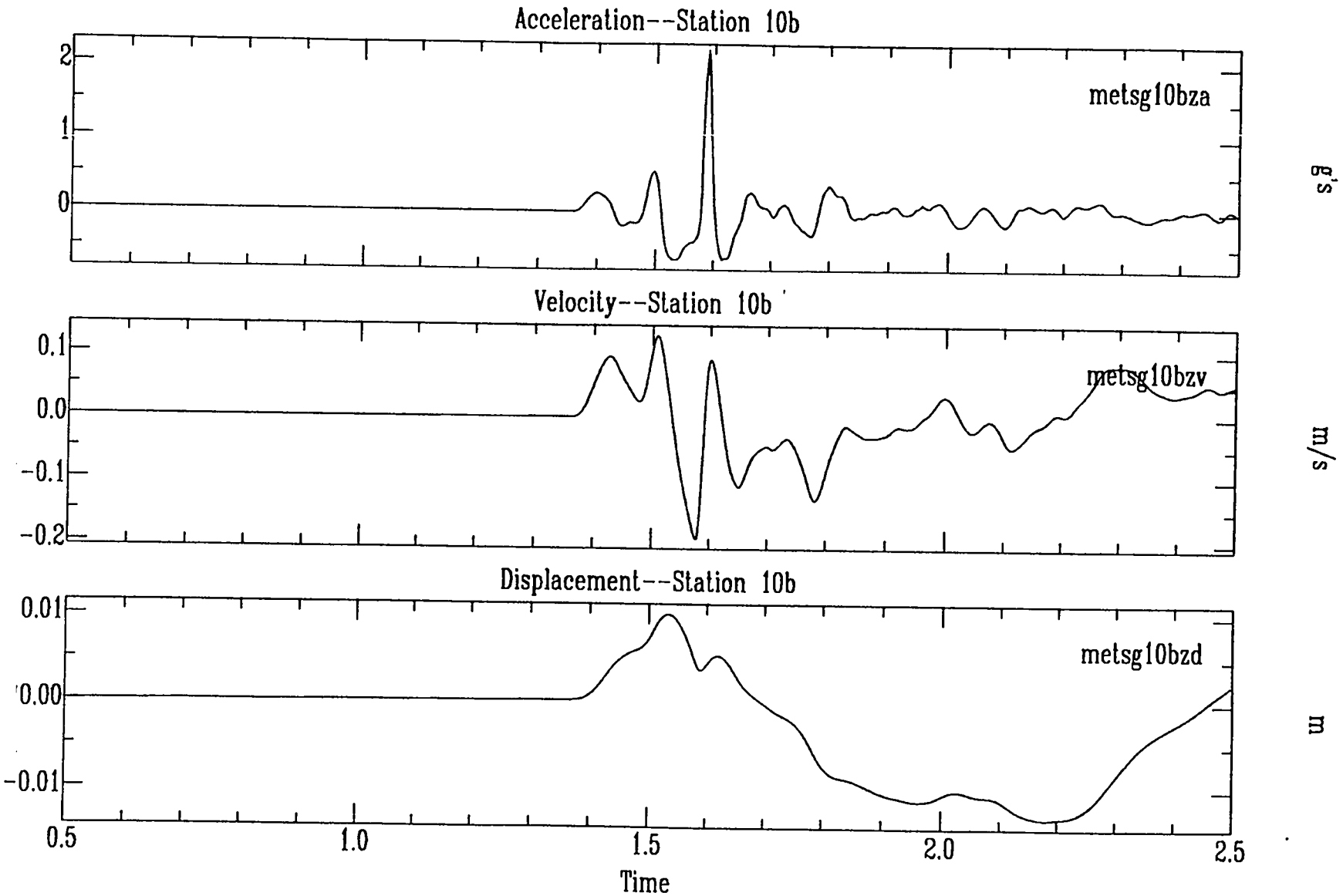


4.8. Mineral Quarry (U12n.22)

Experiment design. The Area 12 tunnel event, Mineral Quarry, had an array of 34 surface ground motion stations: 9 GRMPY (around SGZ, inside the predicted spall zone) and 25 ESA stations (from just outside to well beyond the edge of predicted spall), fielded by SMU and DNA/A (see Table 12 and Fig. 15).

Results. The records for the accelerometer stations fielded on Mineral Quarry are given in Fig. 16 (32 pages). Of the nine GRMPY stations fielded, seven recorded good spall signals and two, MINGR7A and 8A, recorded signals that indicated that the stations were just at the edge of spall. Of the 25 planned ESA stations, five (including MINSG3A, 5A, 14A, 15A and the 9-element array) were recorded on DNA PDASs, the data from which were not available as this report went to press. None of the ESA stations recorded signals that indicated spall.

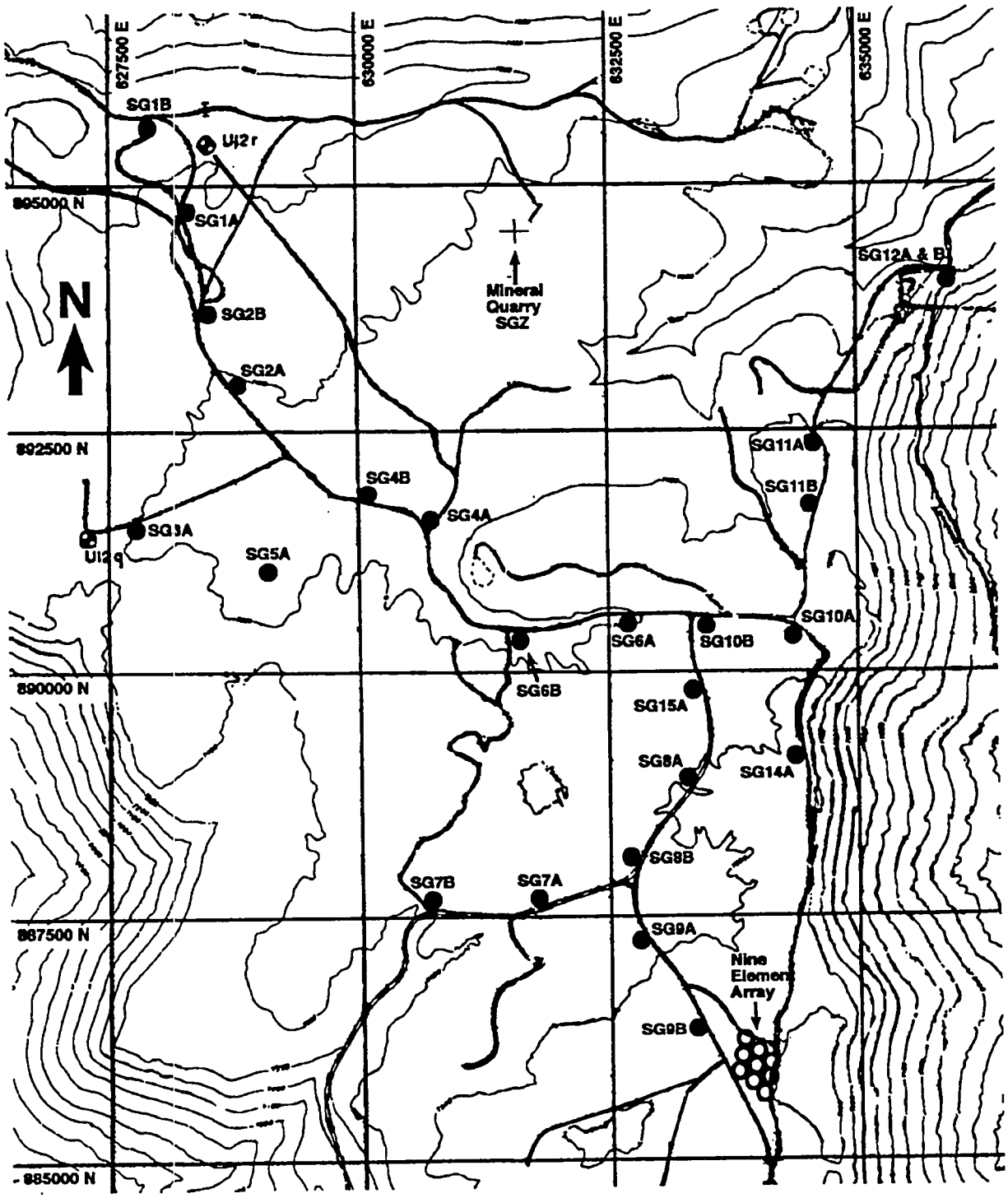
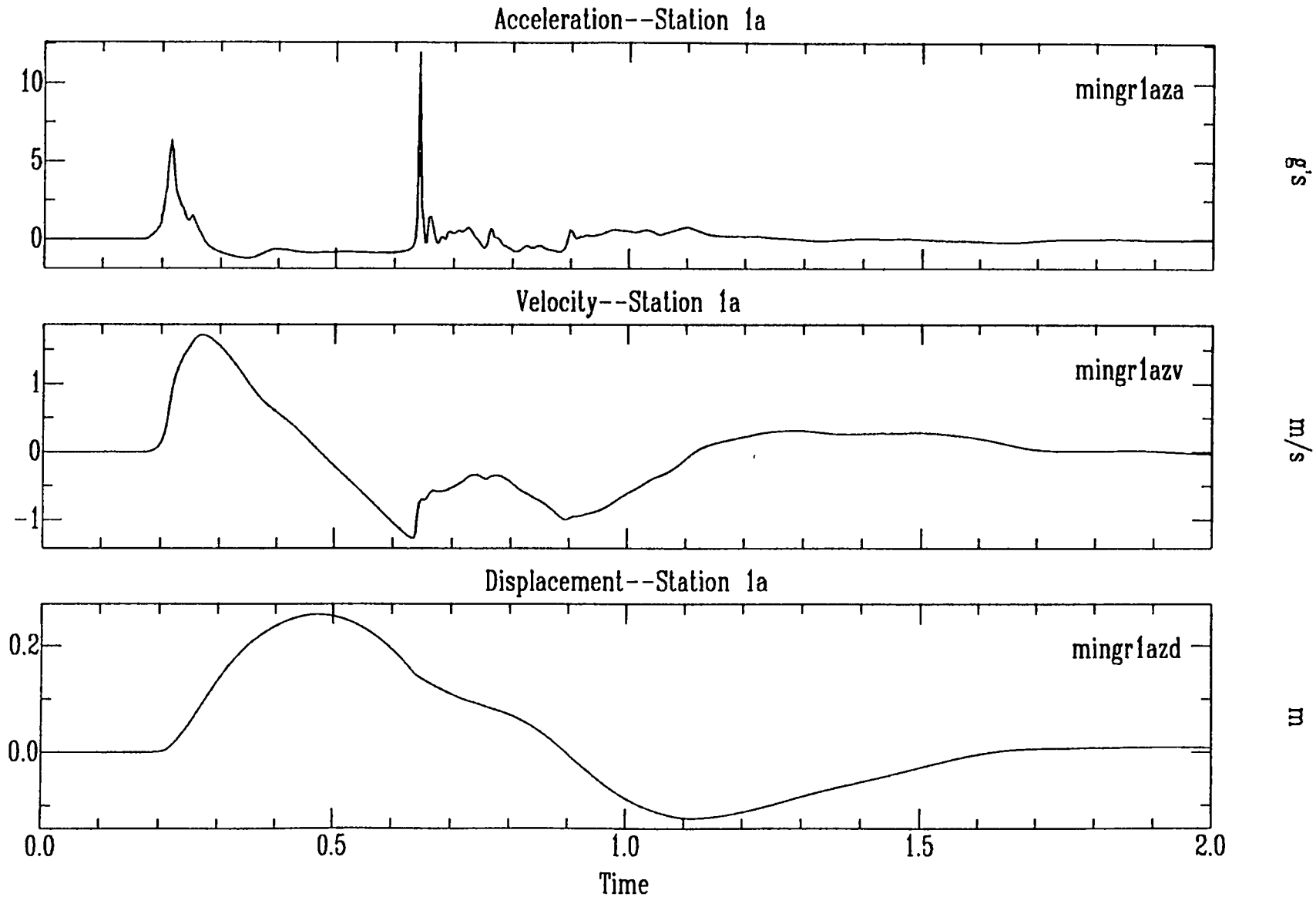


Fig. 15. Mineral Quarry station map.

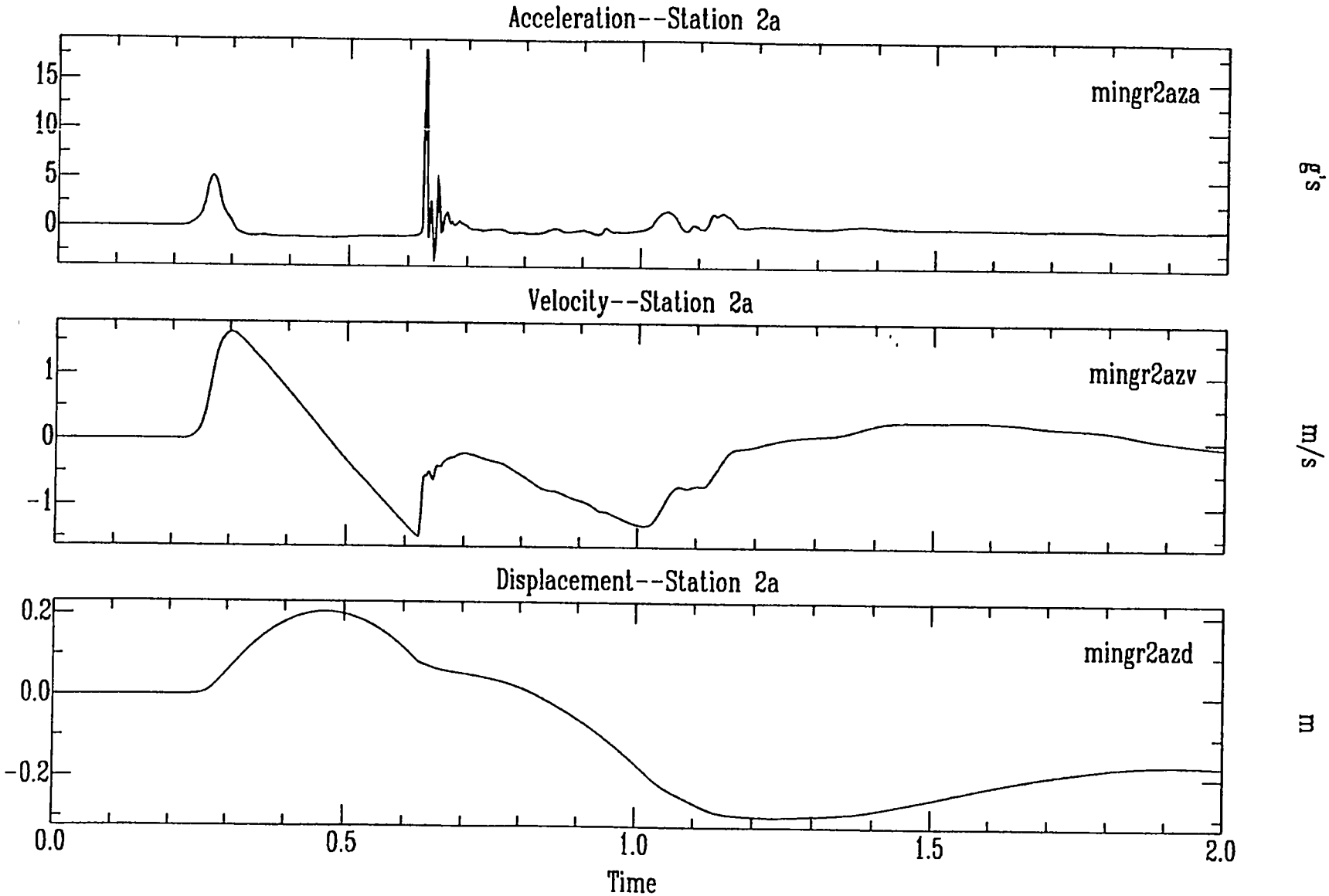
Table 12. Mineral Quarry SIG Data

Station Name	Station Loc u12n.22	Accelerometer	Northing (m) 272672	Easting (m) 192557	Slant Range (m) DOB	Travel Time
MINGR1A	30 m N24E		272700	192570	401	0.173
MINGR1B	30 m N24E		272700	192570	401	0.171
MINGR1C	30 m N24E		272700	192570	401	0.173
MINGR2A	205 m N07W		272876	192531	450	0.22
MINGR3A	423 m N59E		272893	192919	583	0.3
MINGR4A	436 m S41E		272345	192846	592	0.253
MINGR5A	221 m S51W		272535	192385	456	0.198
MINGR6A	390 m N18W		273044	192440	559	0.297
MINGR7A	675 m N57W		273043	191993	785	0.435
MINGR8A	580 m N71E		272857	193108	706	0.354
MINGR9A			273083	192408	593	0.331
MINSG1A	1055 m N86W	Terra Tec 3.7 g	272745	191505	1128	5.213
MINSG1B	1195 m N74W	Terra Tec 5.28 g	272995	191405	1262	5.274
MINSG2A	1025 m S59W	Terra Tec 3.7 g	272150	191675	1100	5.132
MIN SG2B	1035 m S74W	Terra Tec 5.28 g	272385	191565	1107	5.157
MINSG4A	965 m S18W	Terra Tec 3.7 g	271755	192255	1045	4.96
MINSG4B	965 m S30W	Terra Tec 5.28 g	271840	192070	1044	4.996
MINSG6A	1315 m S16E	Terra Tec 3.7 g	271410	192920	1373	5.199
MINSG6B	1295 m S2W	Terra Tec 5.28 g	271380	192515	1353	5.213
MINSG7A	2130 m S8E	Terra Tec 3.7 g	270565	192860	2166	4.956
MINSG7B	2140 m S8W	Terra Tec 5.28 g	270555	192255	2176	4.981
MINSG8A	1800 m S15E	Terra Tec 3.7 g	270935	193030	1844	5.254
MIN SG8B	1995 m S8E	Terra Tec 5.28 g	270700	192840	2032	5.282
MINSG9A	2285 m S8E	Terra Tec 3.7 g	270410	192885	2320	4.985
MINSG9B	2500 m S13E	Terra Tec 5.28 g	270240	193135	2532	5.042
MINSG10A	1515 m S31E	Terra Tec 3.7 g	271380	193345	1565	5.289
MINSG10B	1375 m S23E	Terra Tec 5.28 g	271405	193090	1432	5.259
MINSG11A	1115 m S53E	Terra Tec 3.7 g	272000	193445	1183	5.16
MIN SG11B	1215 m S44E	Terra Tec 5.28 g	271790	193395	1281	5.09
MINSG12A	1120 m S77E	Terra Tec 3.7 g	272415	193645	1187	5.053
MINSG12B	1275 m S82E	Terra Tec 5.28 g	272490	193820	1337	5.053

Mineral Quarry Surface Ground Motion



Mineral Quarry Surface Ground Motion



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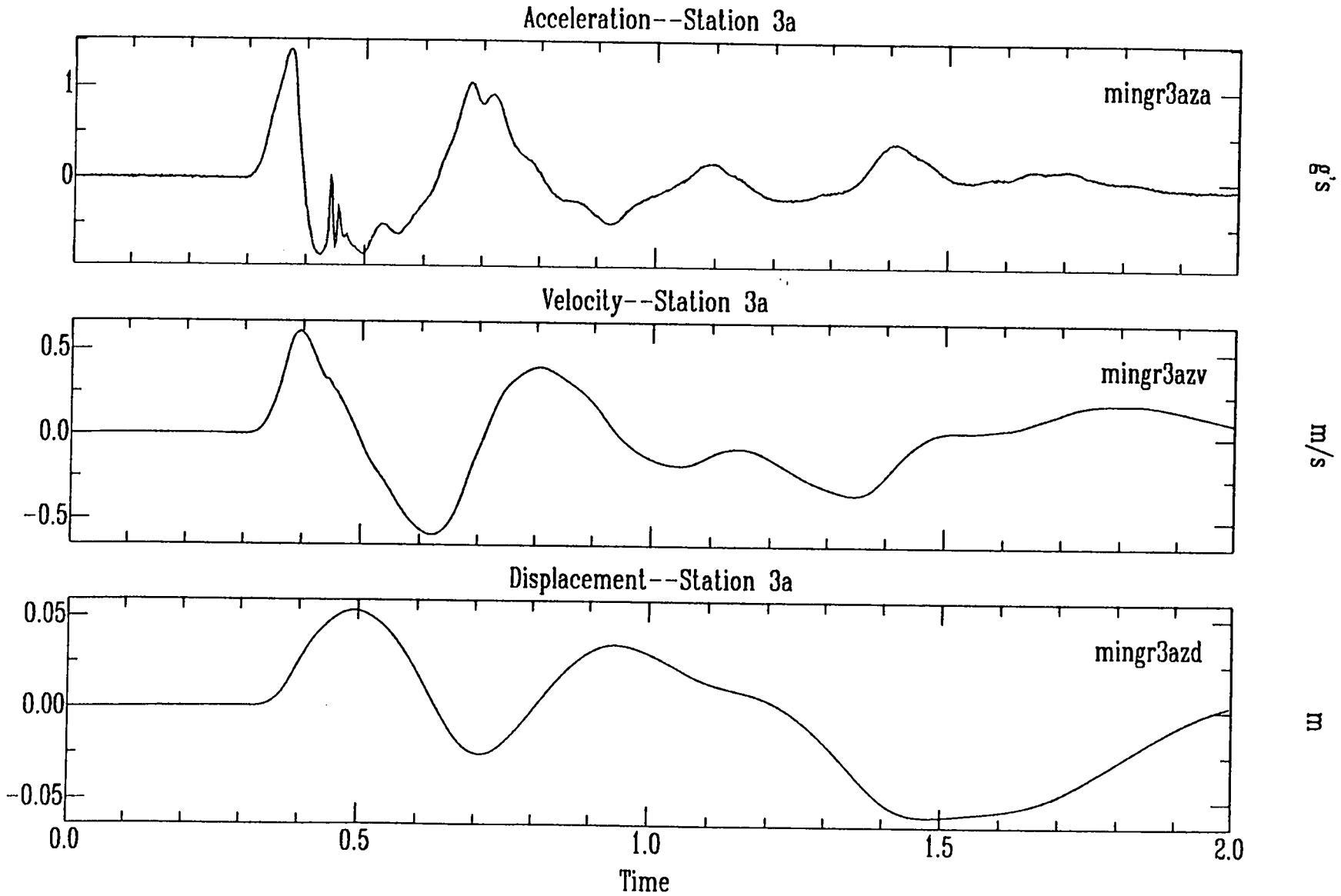

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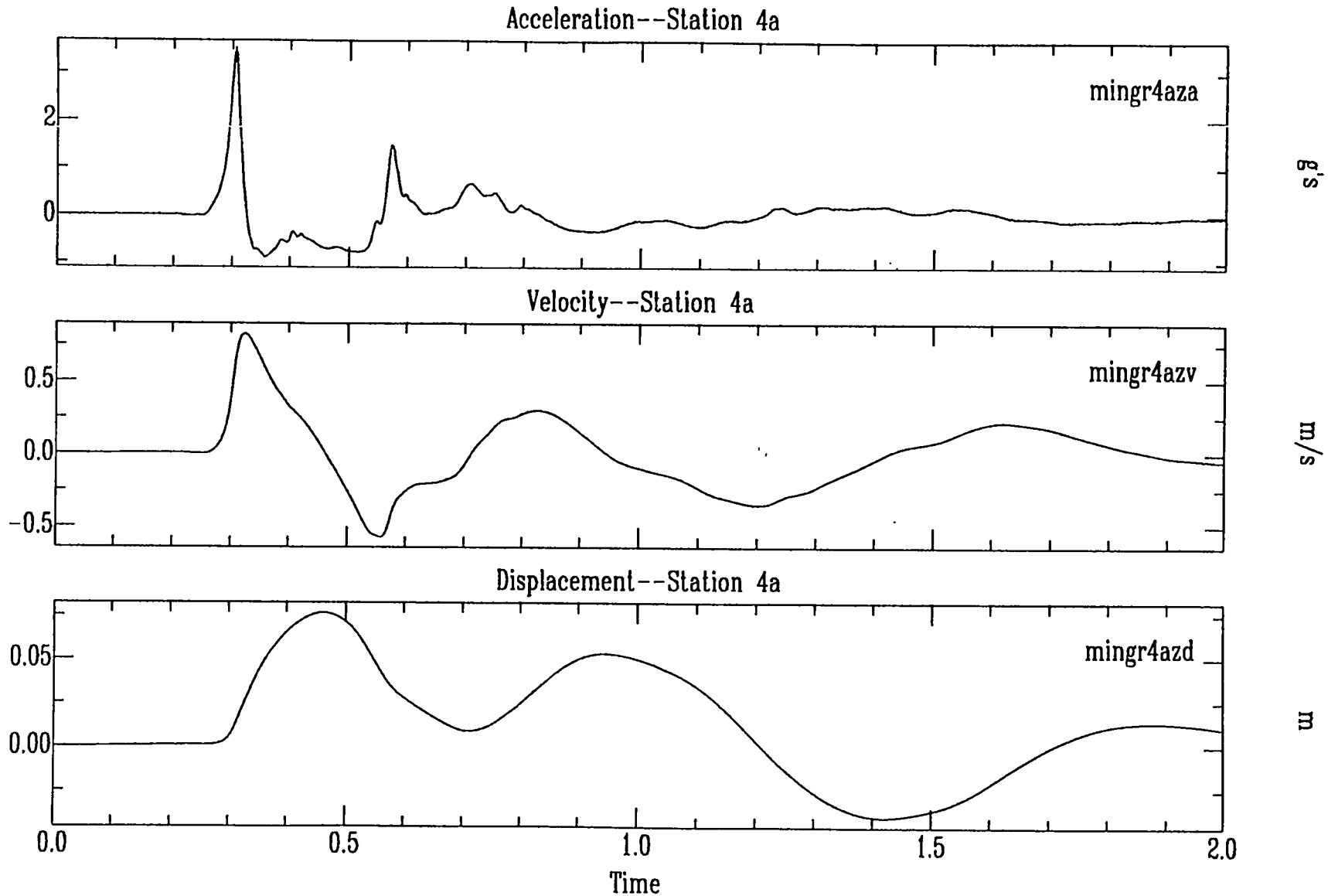

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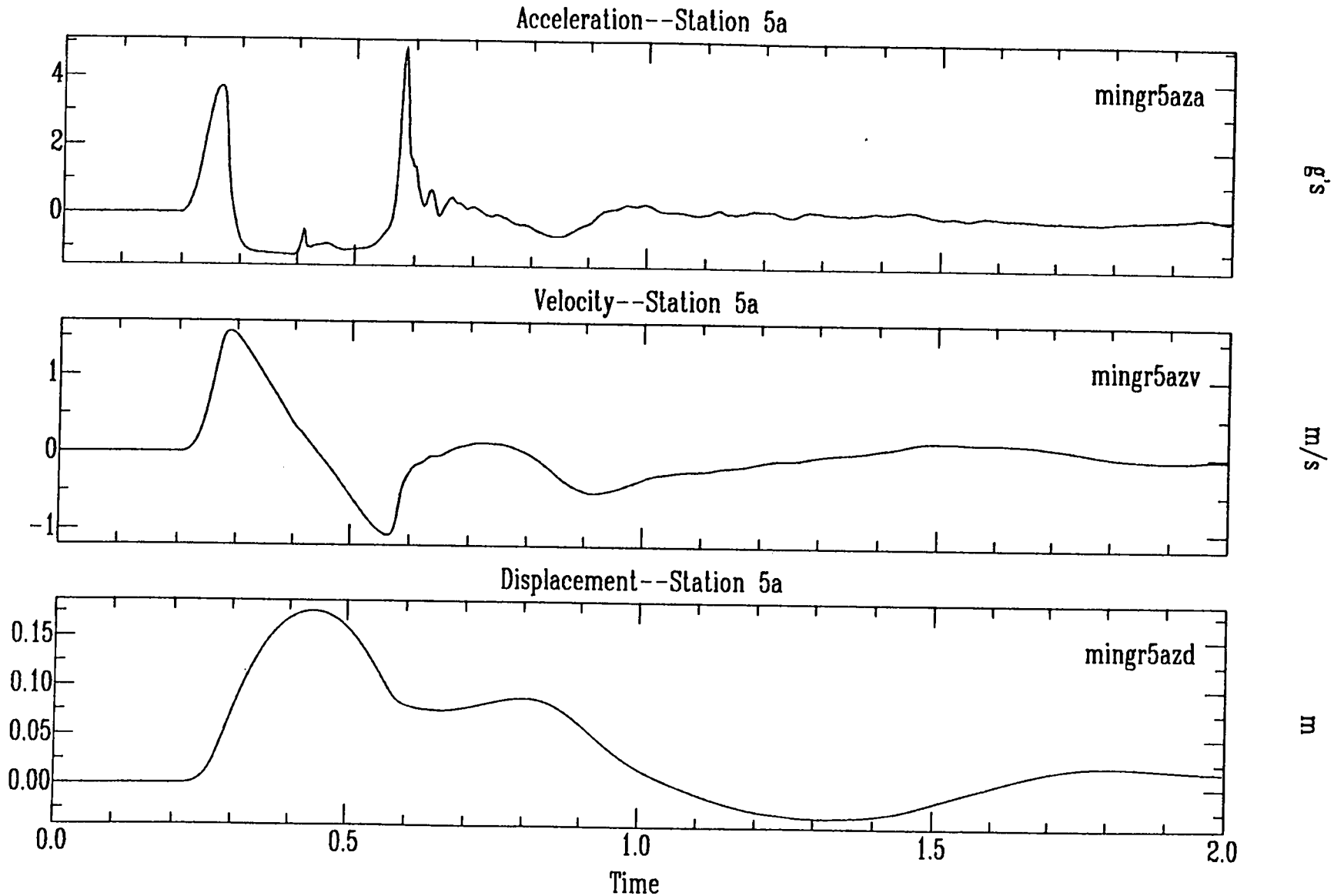

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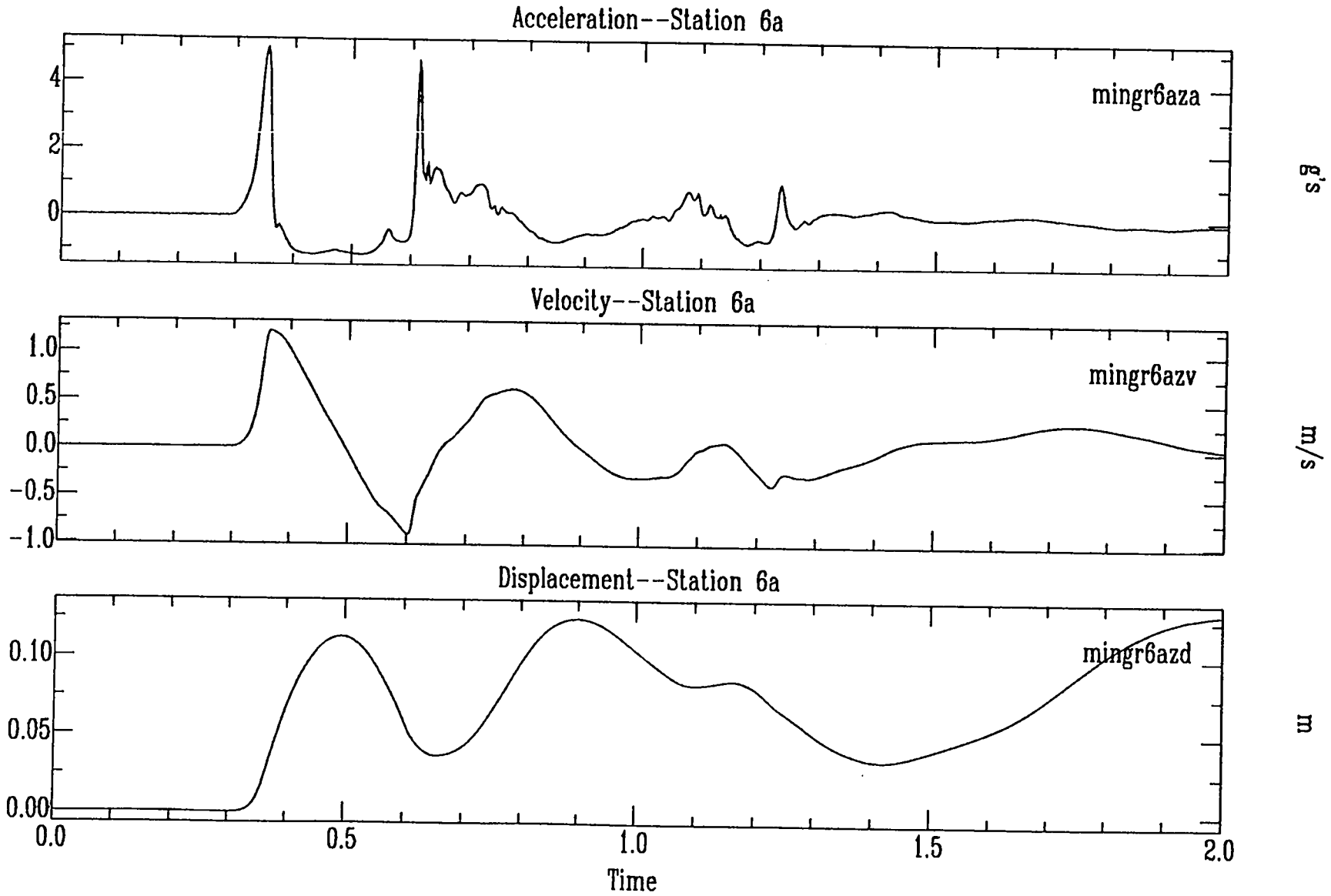

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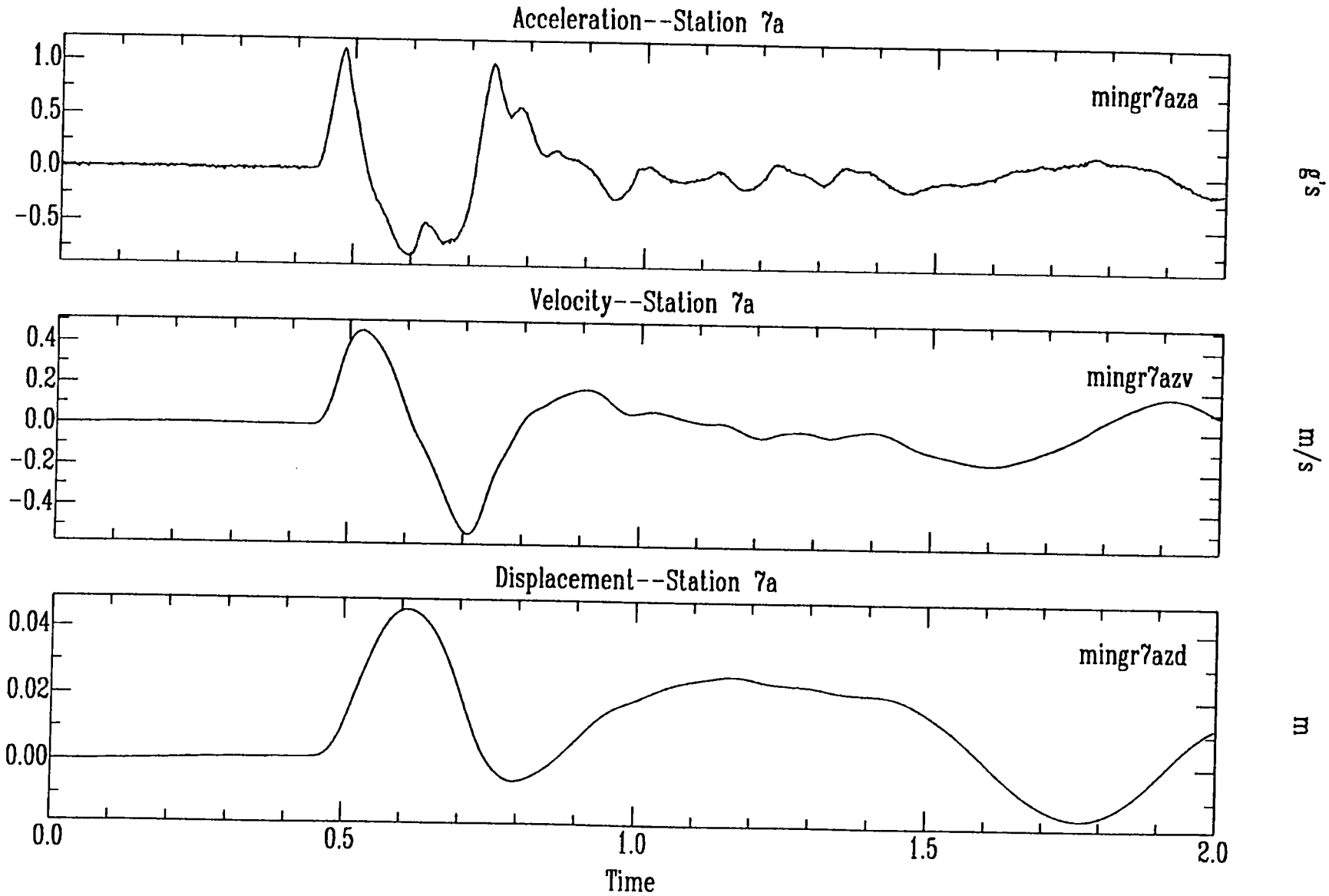

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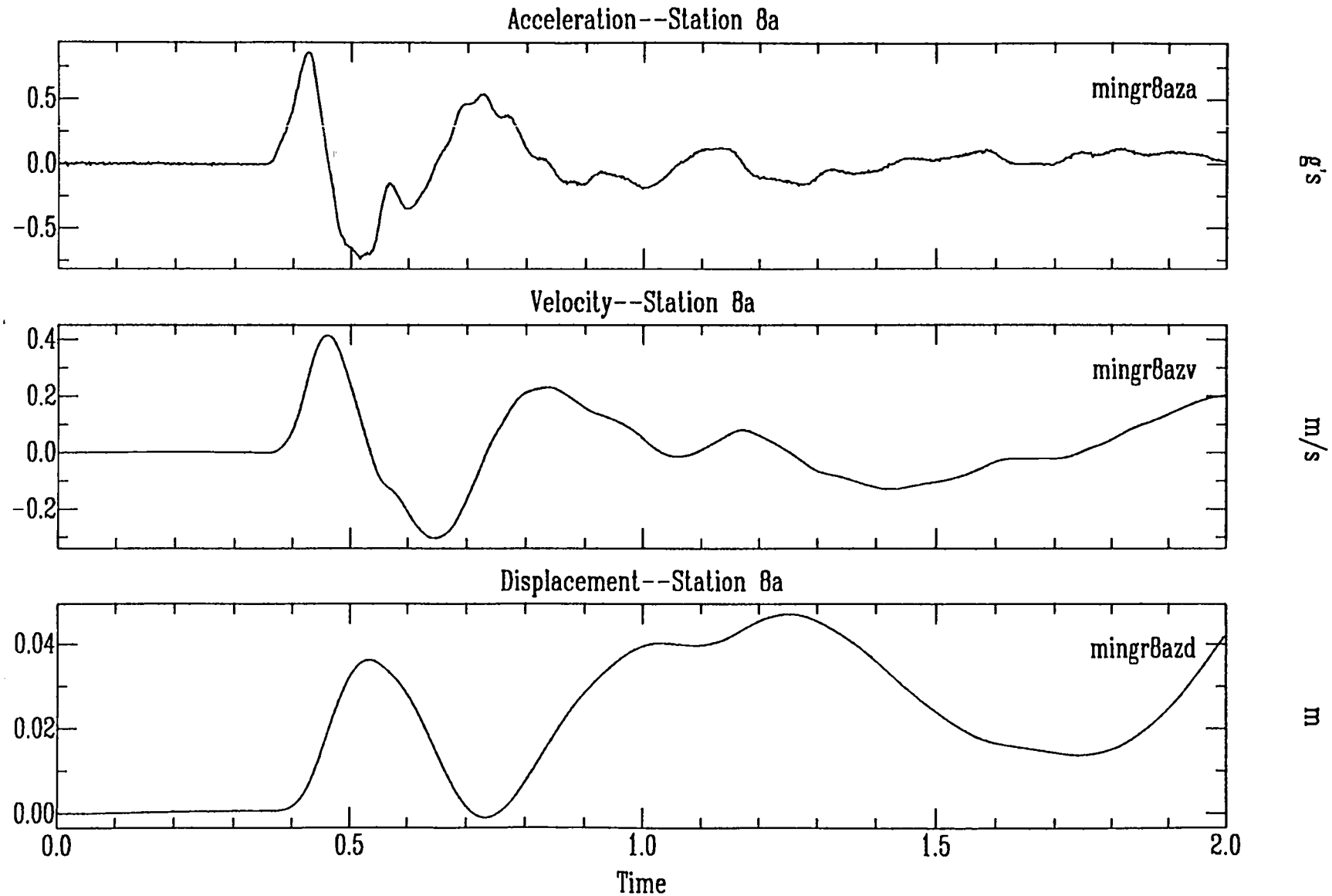

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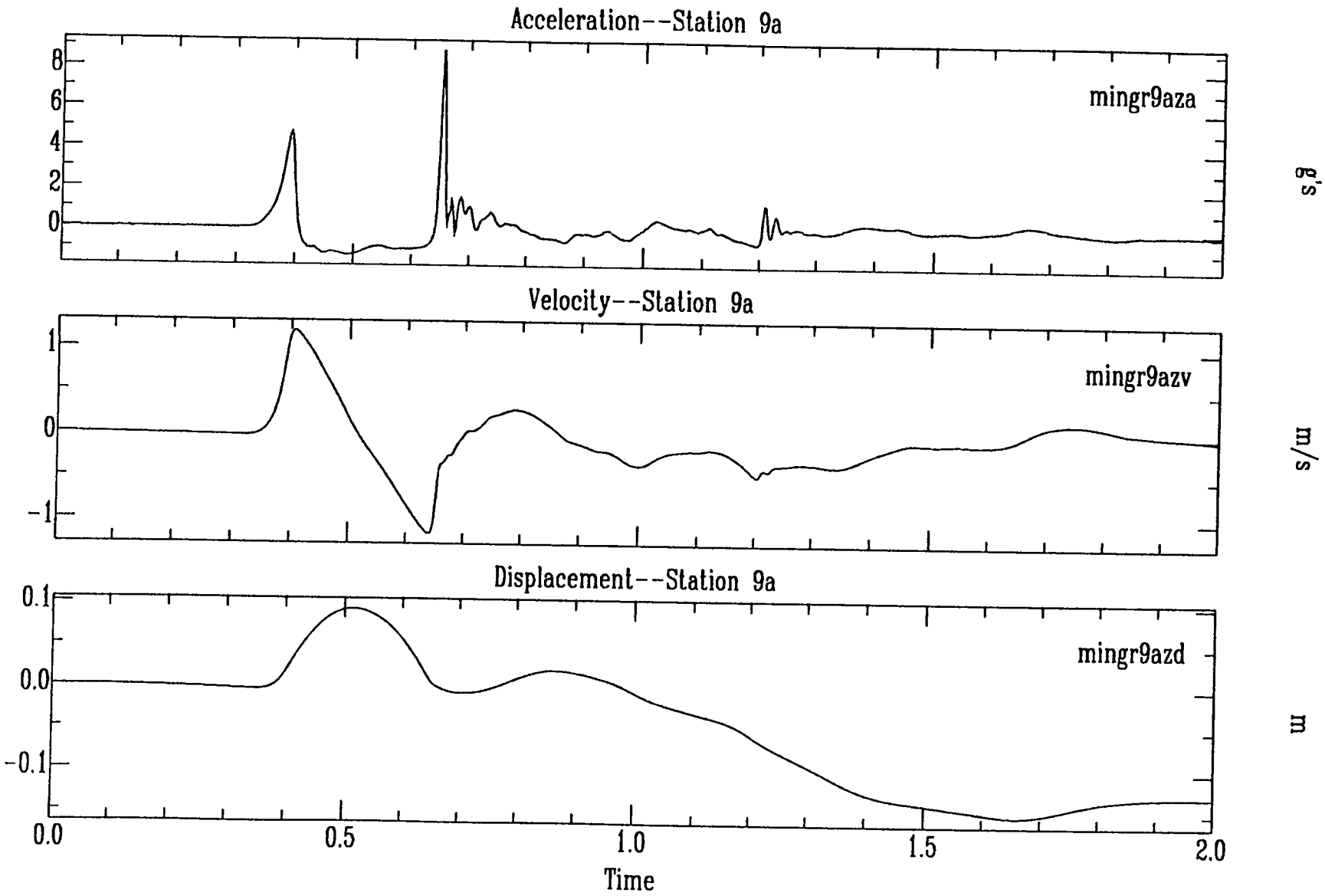

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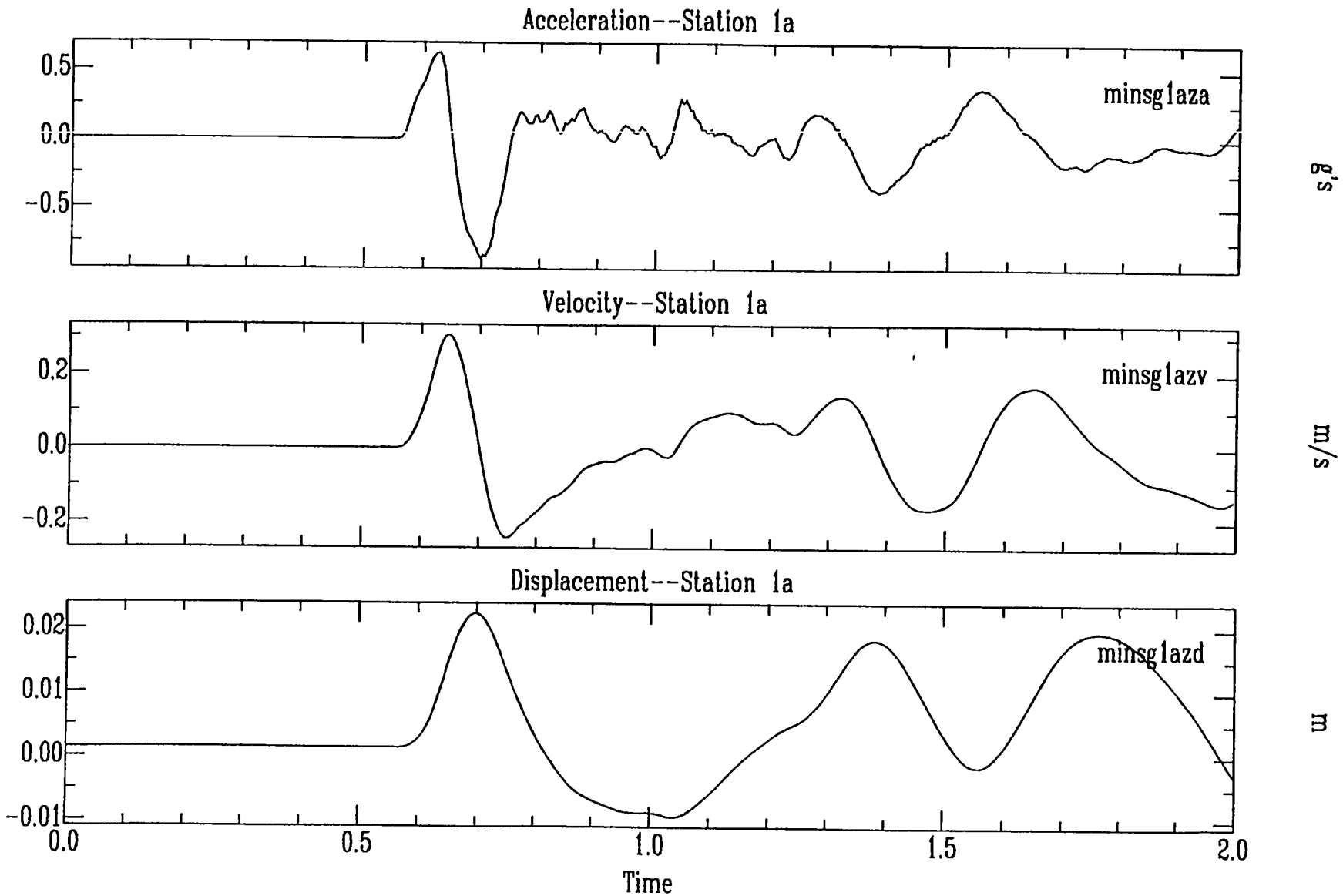

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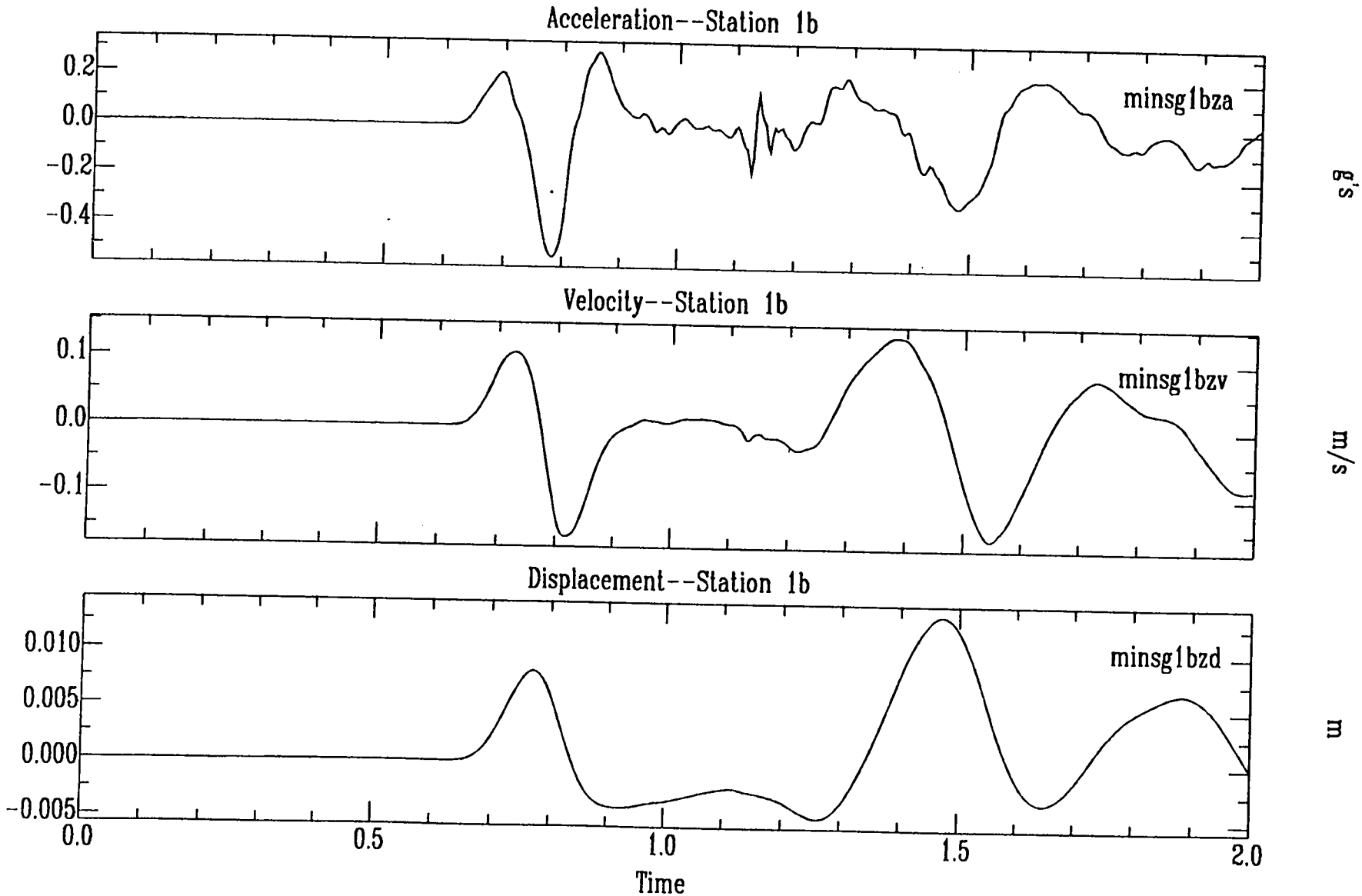

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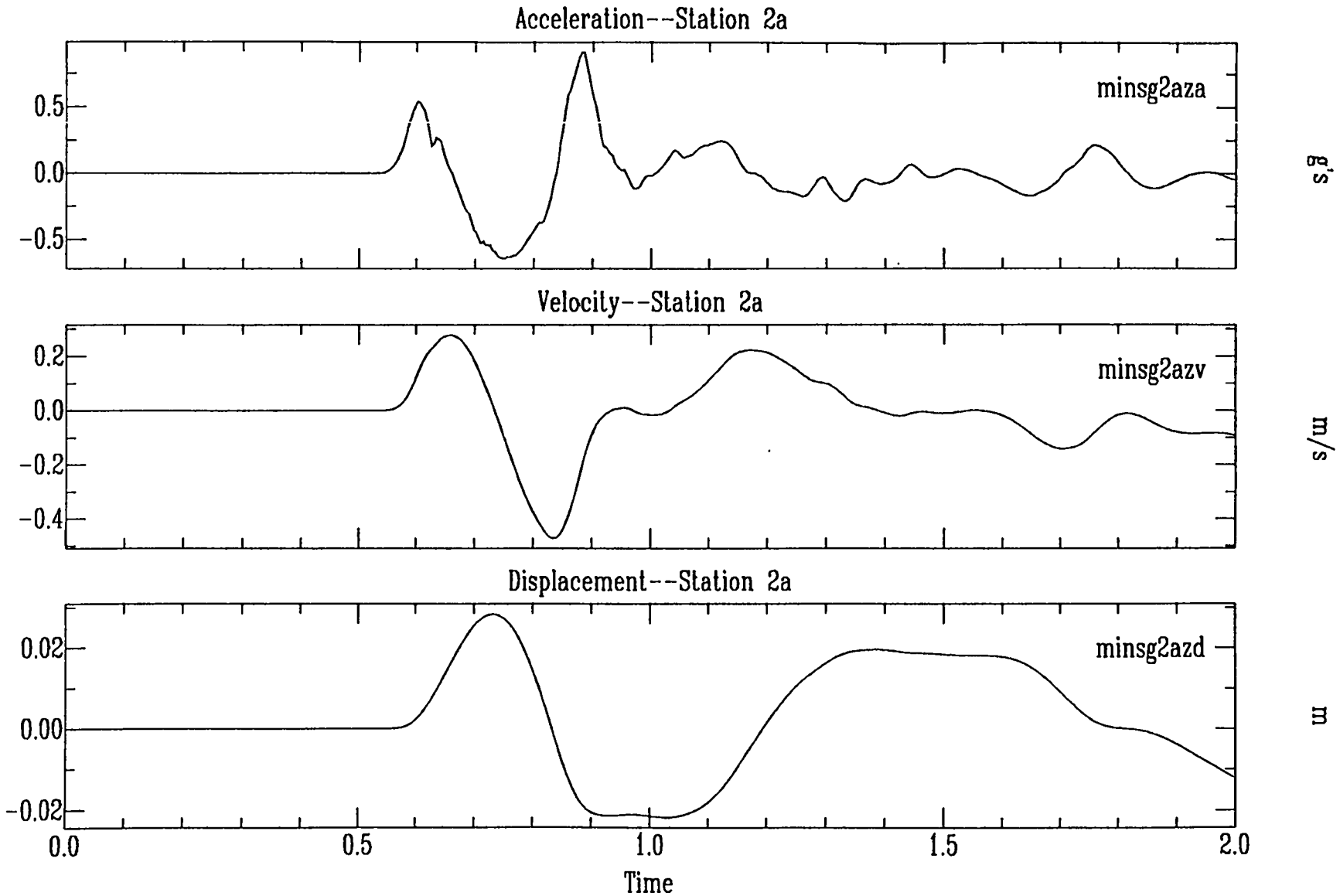

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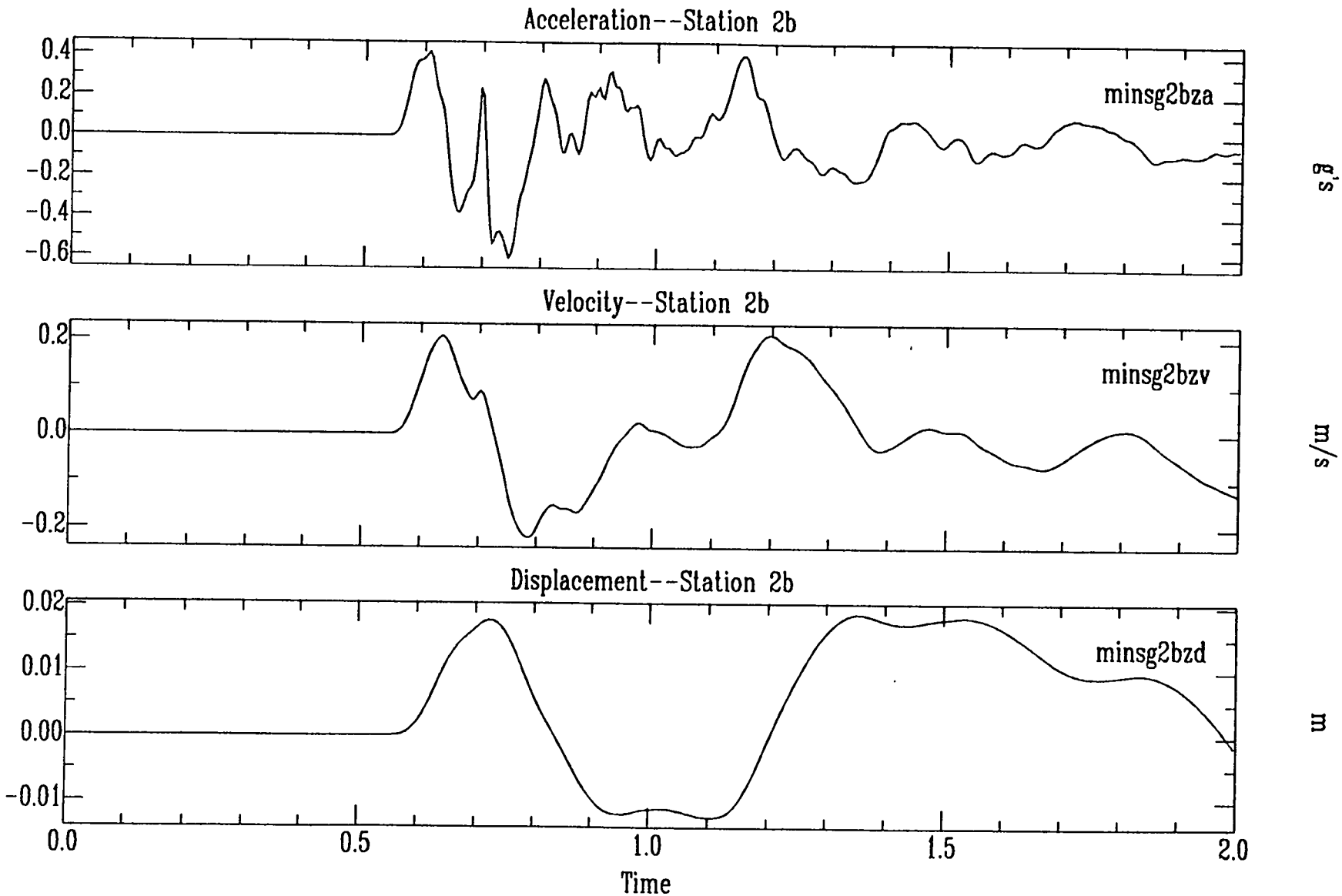

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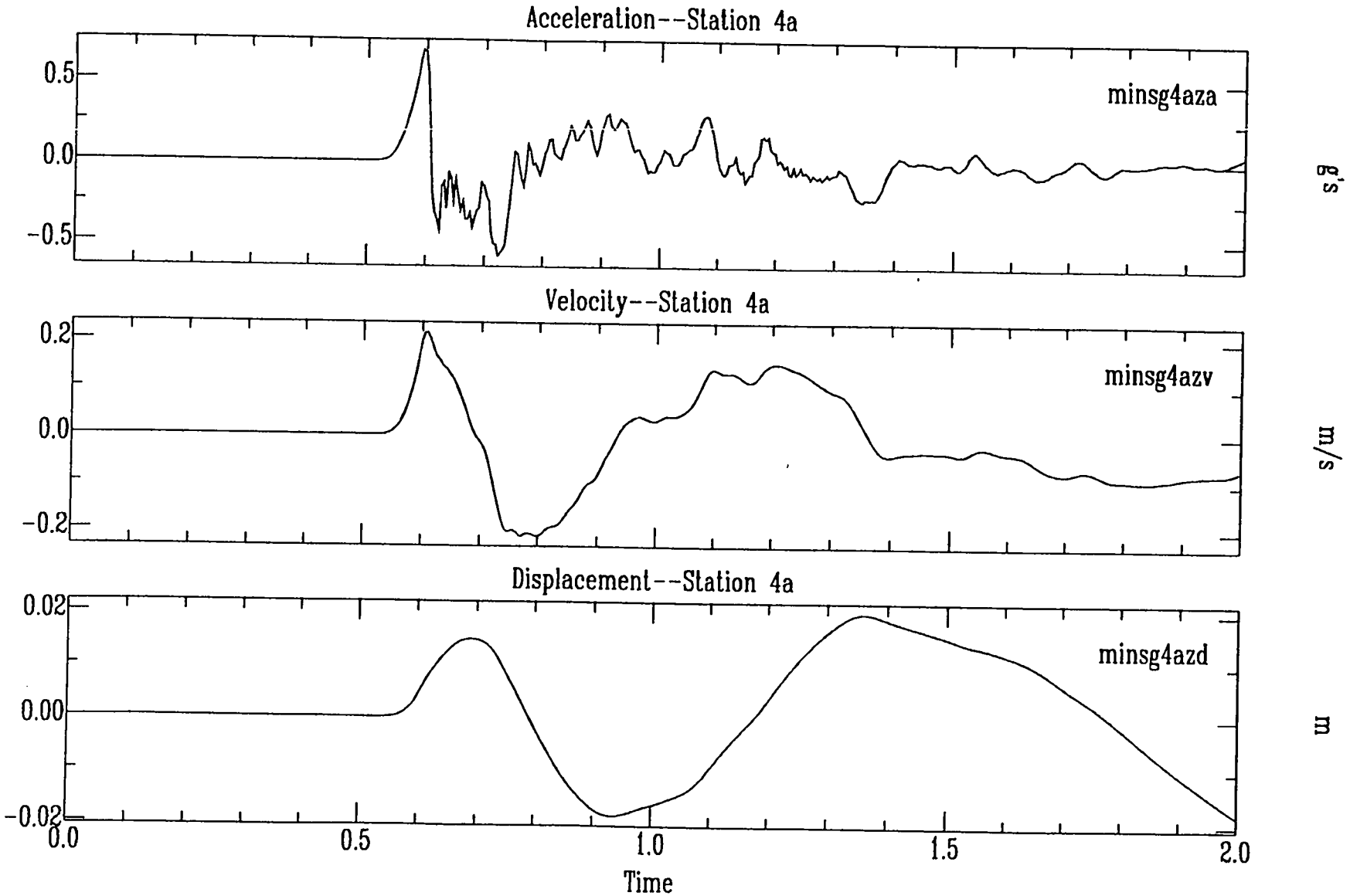

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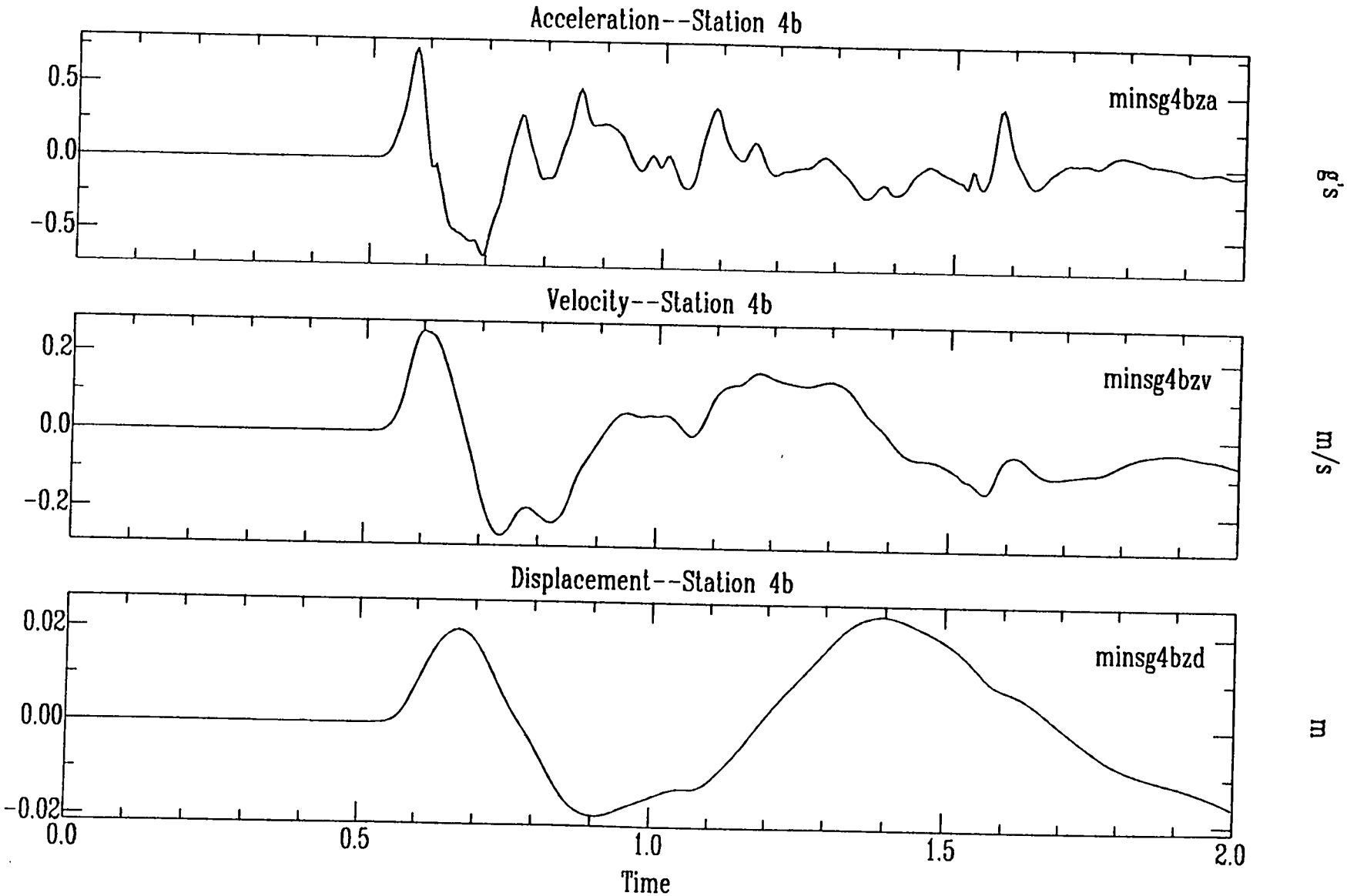

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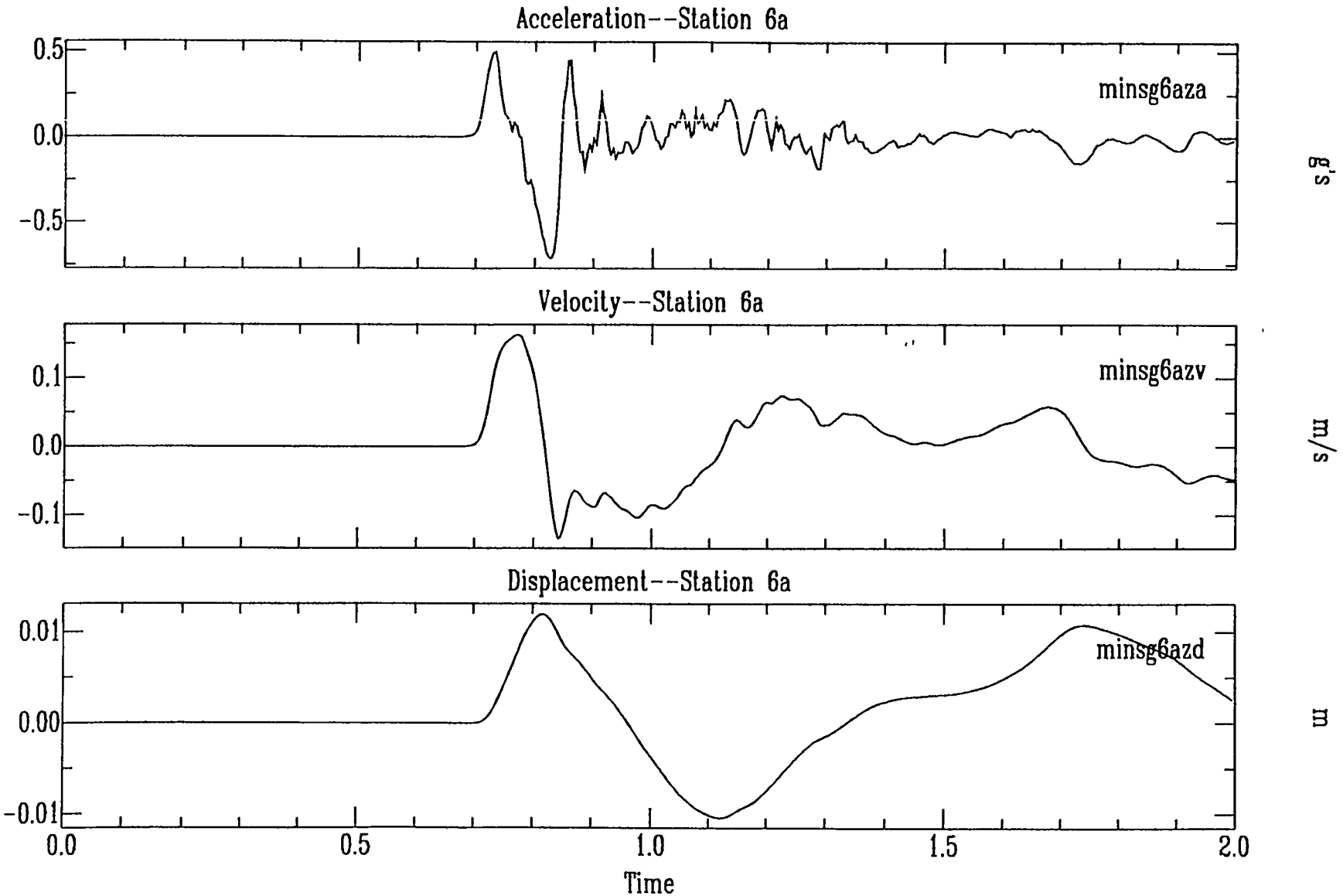

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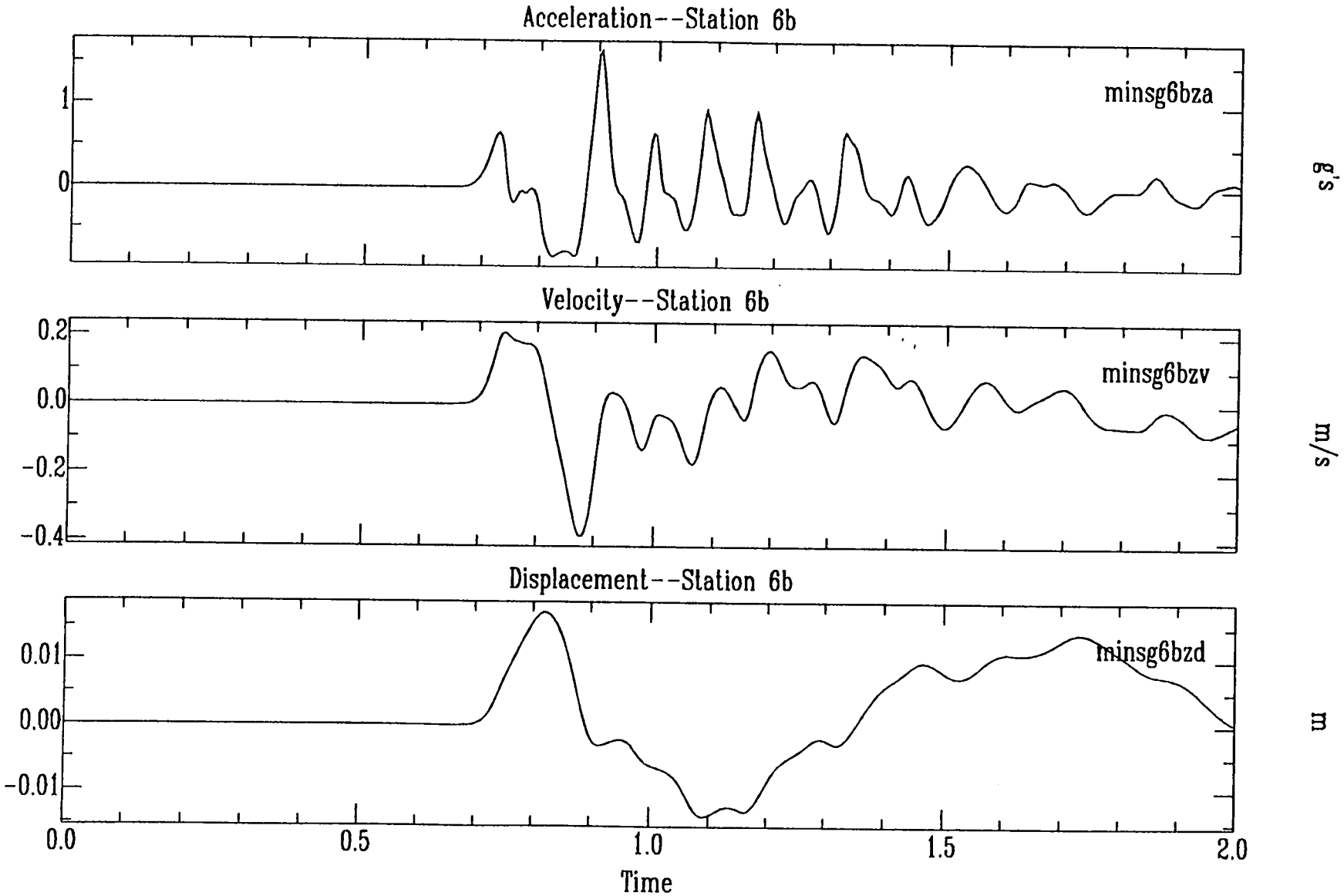

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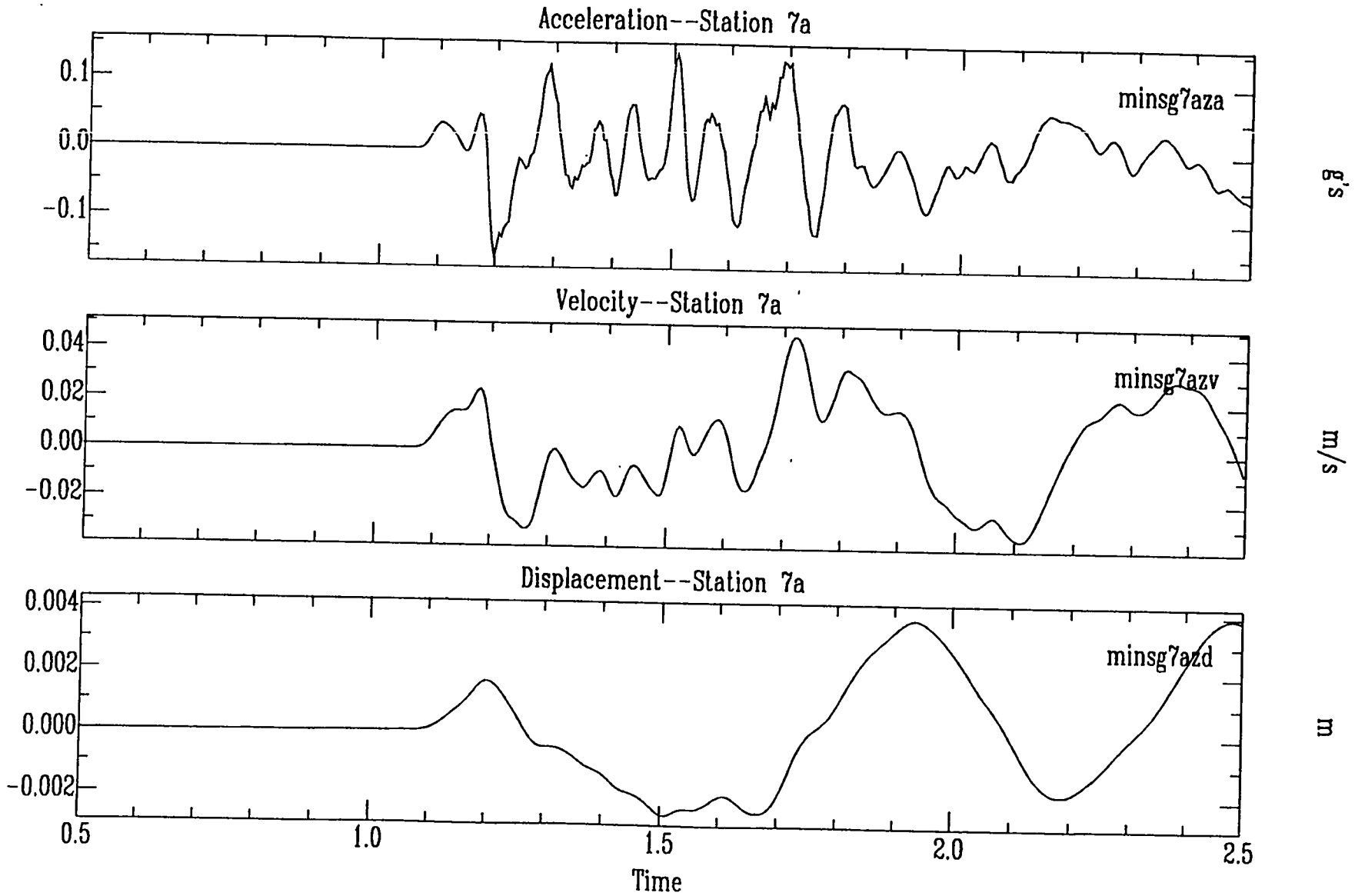

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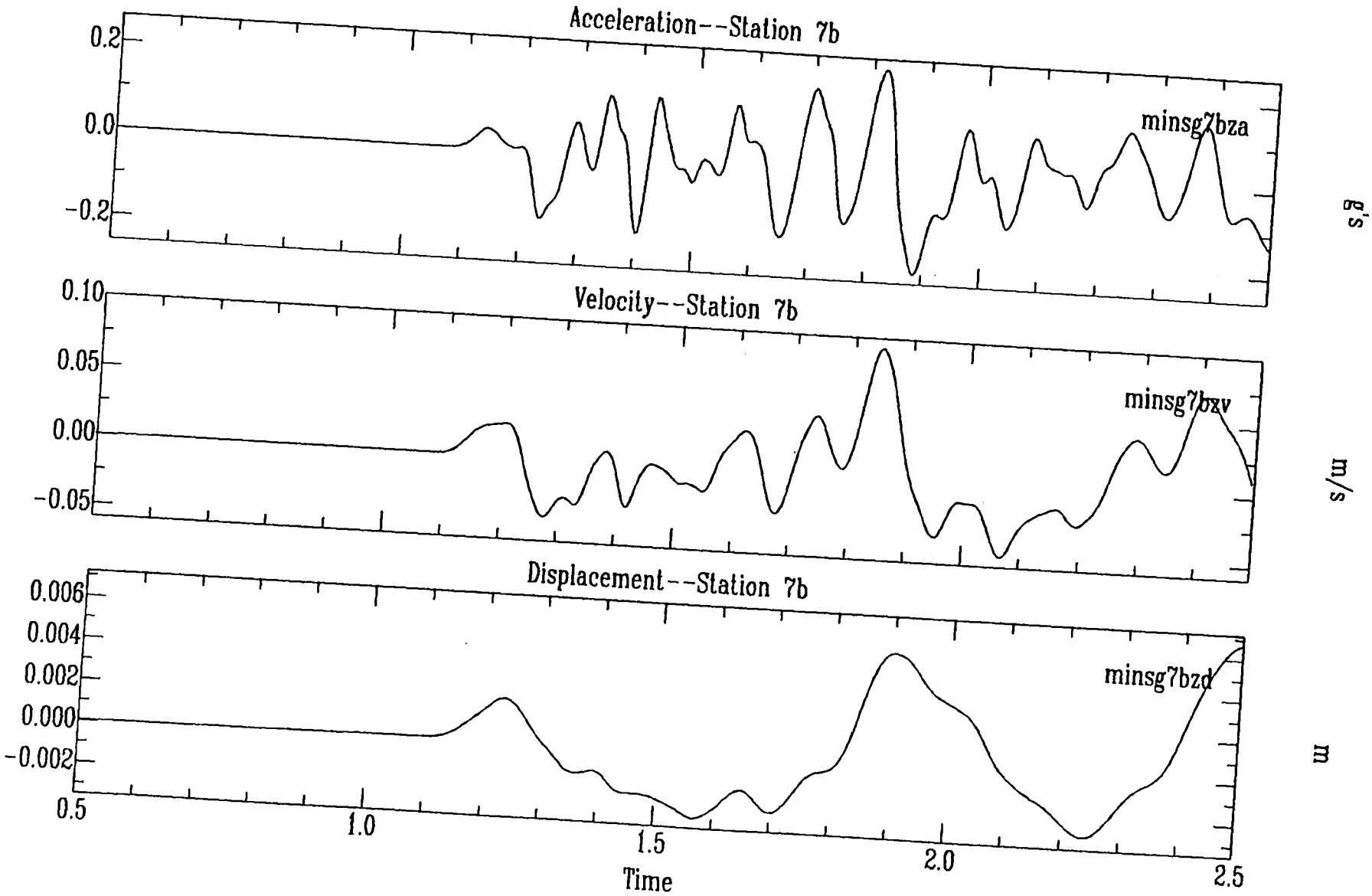

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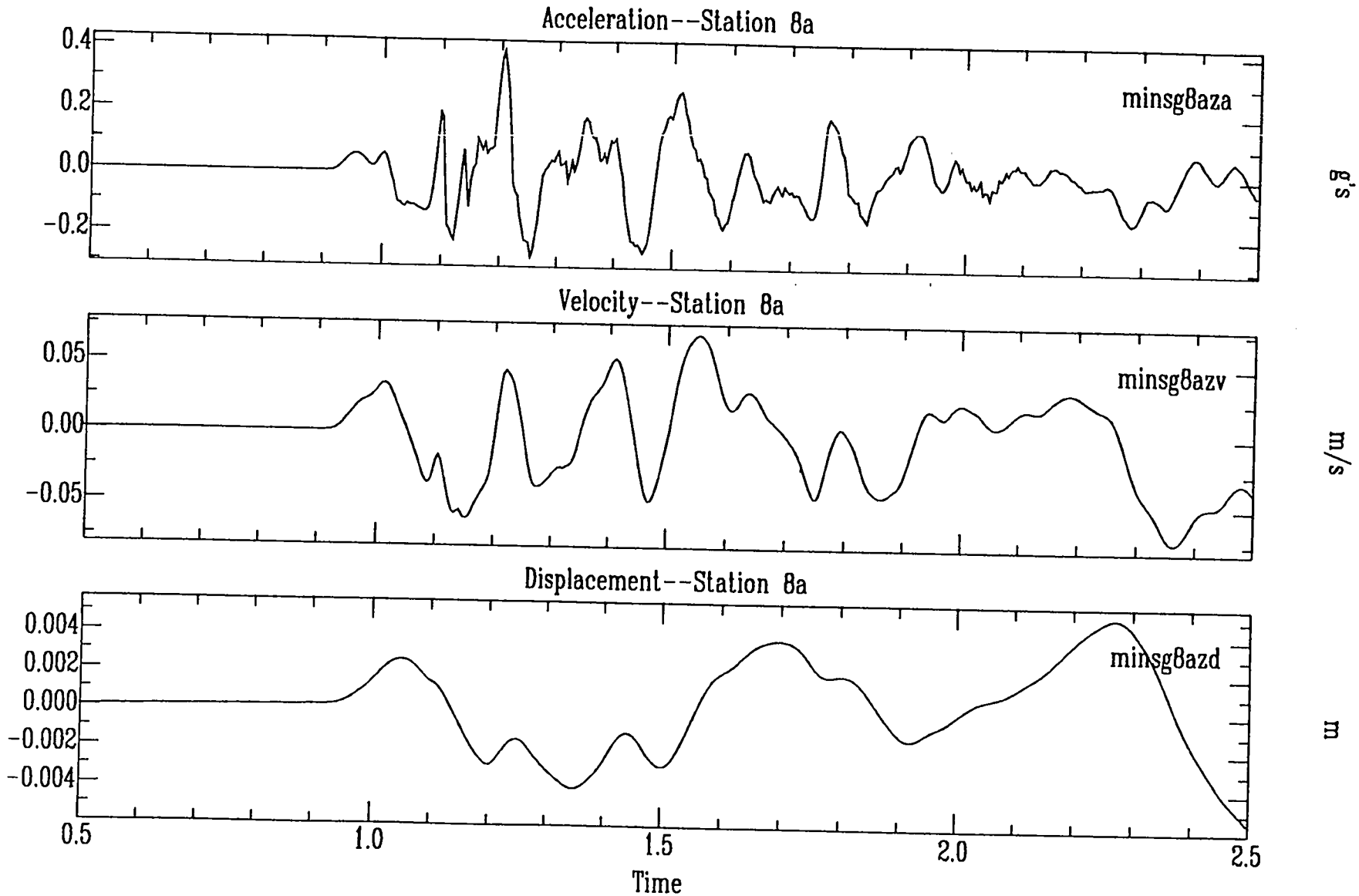

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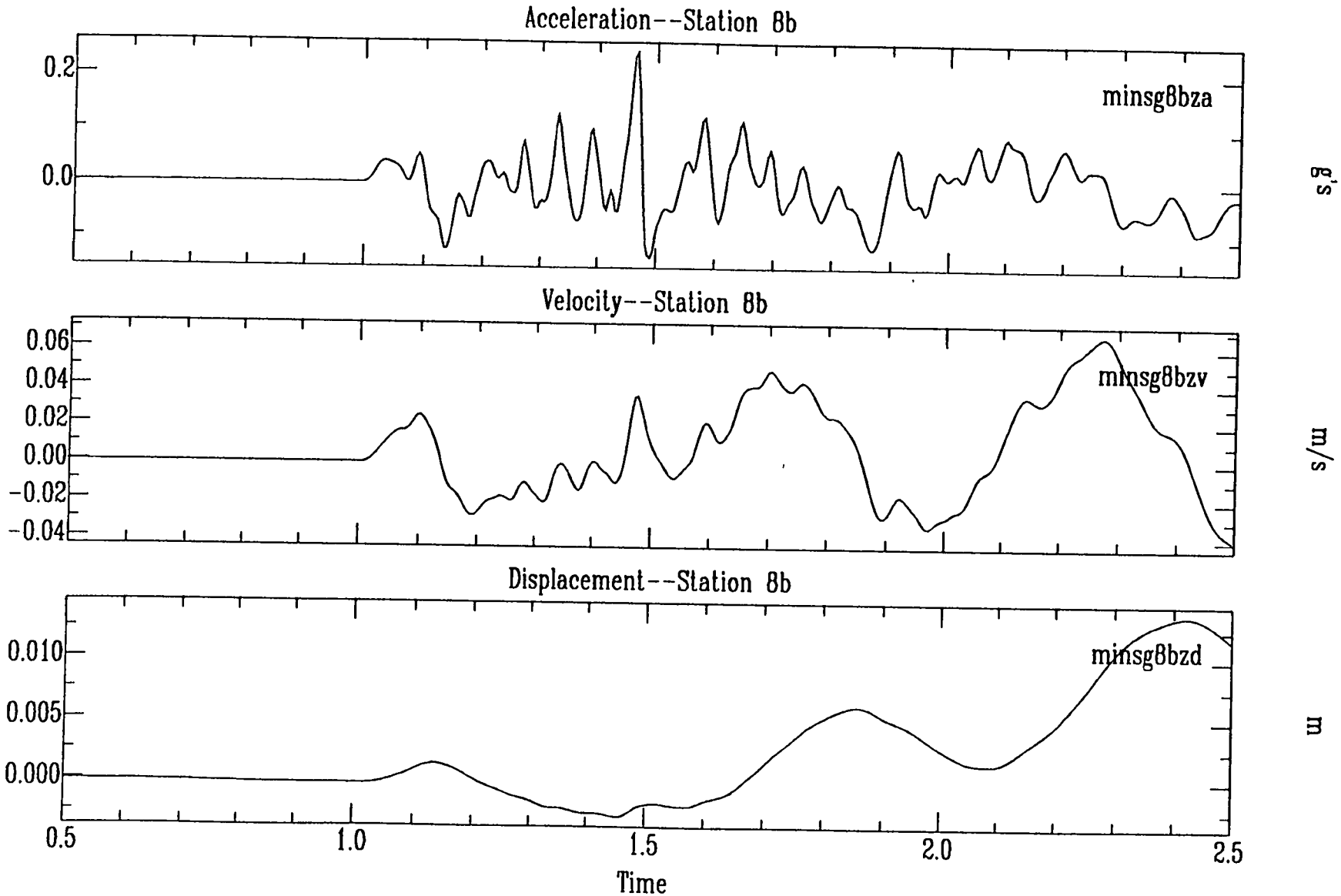

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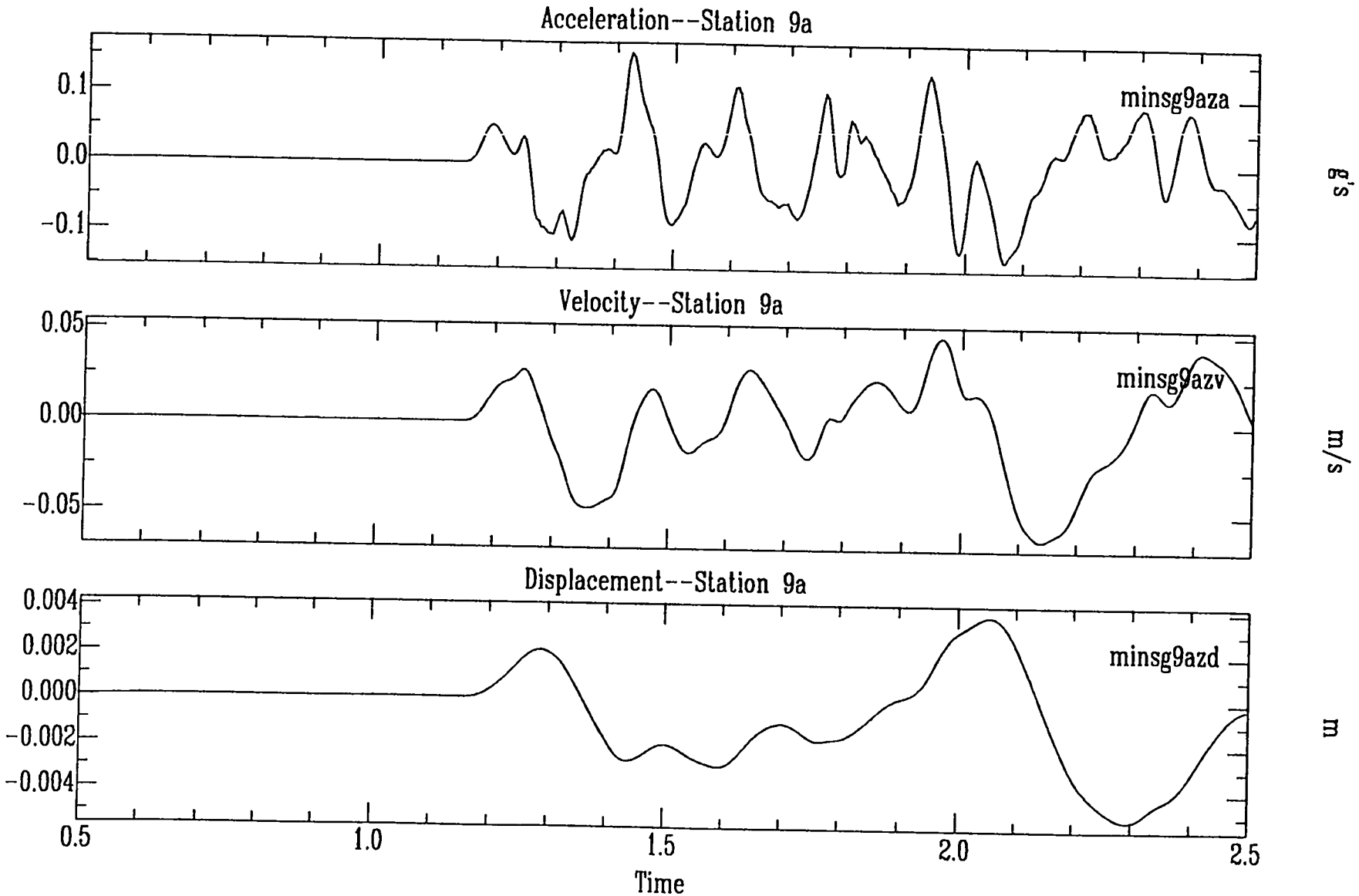
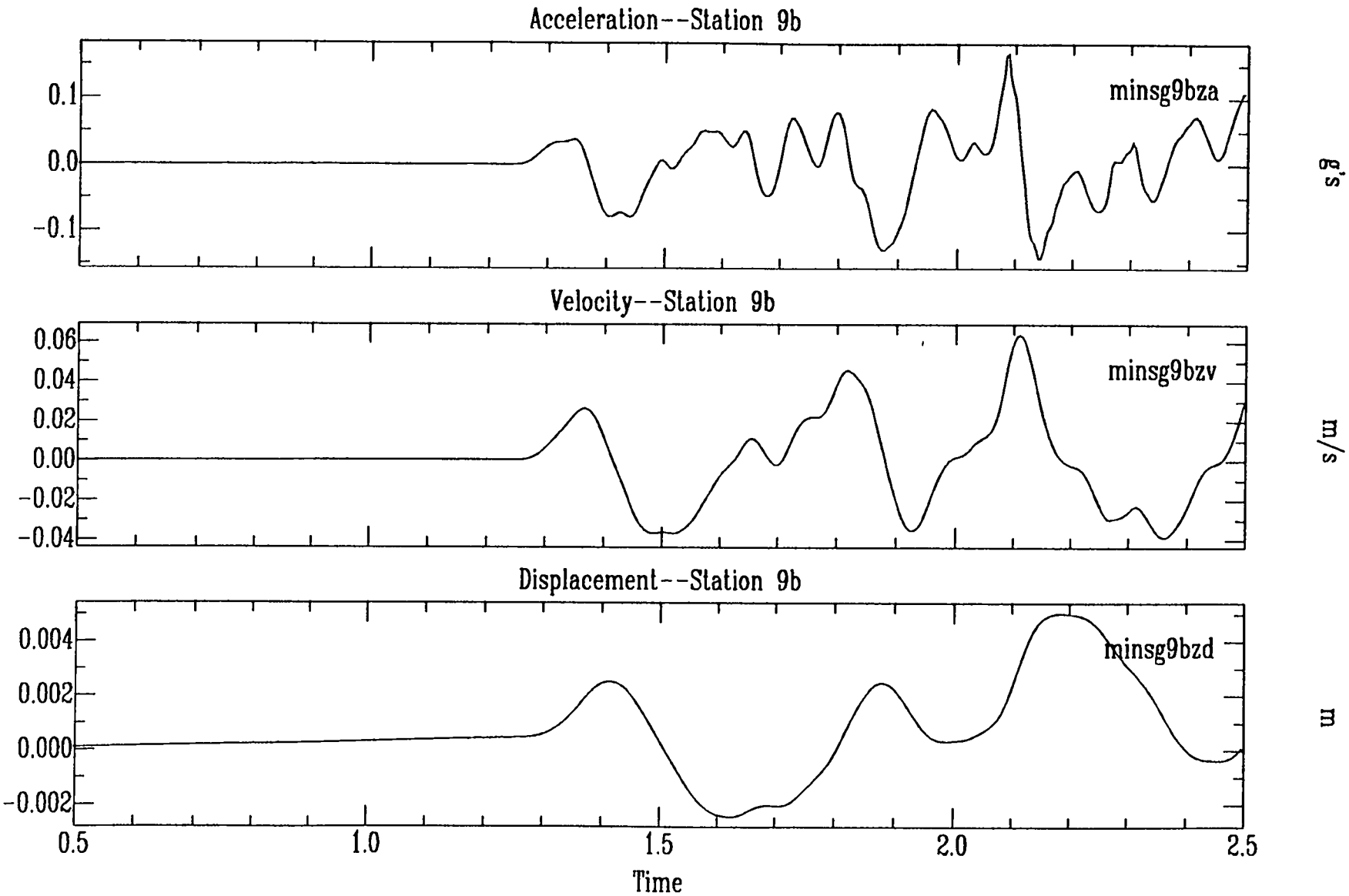


Mineral Quarry Surface Ground Motion



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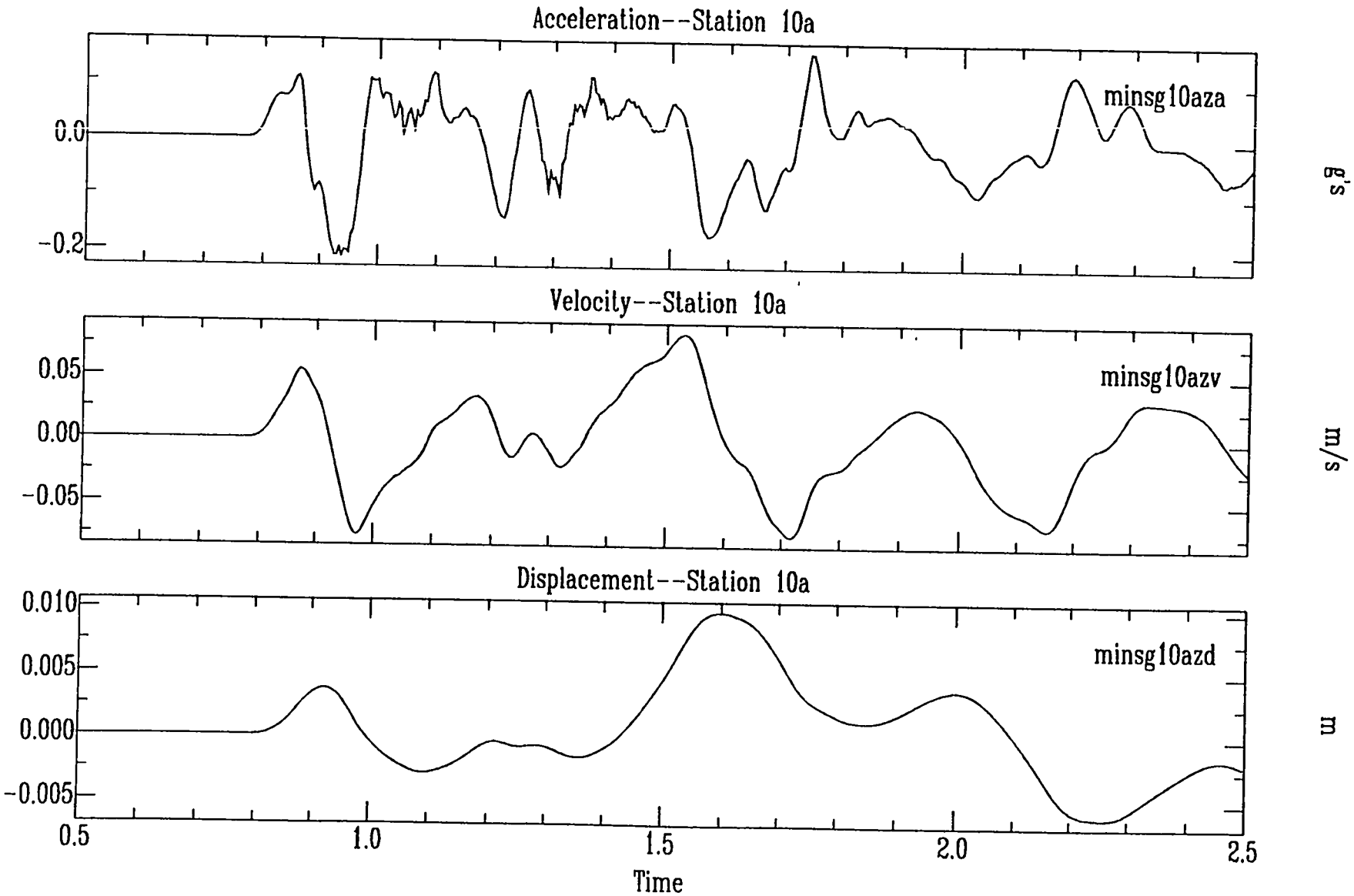
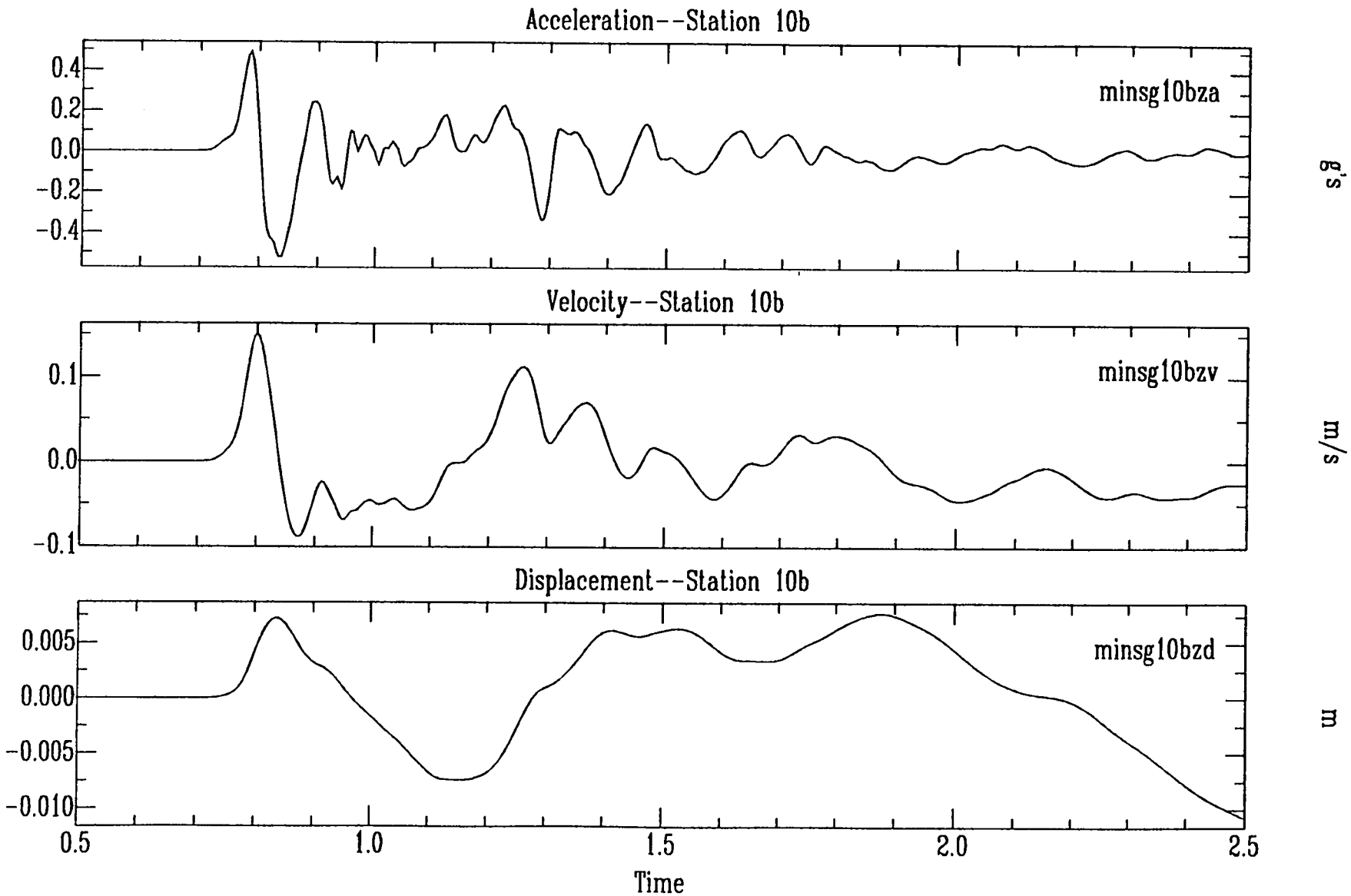
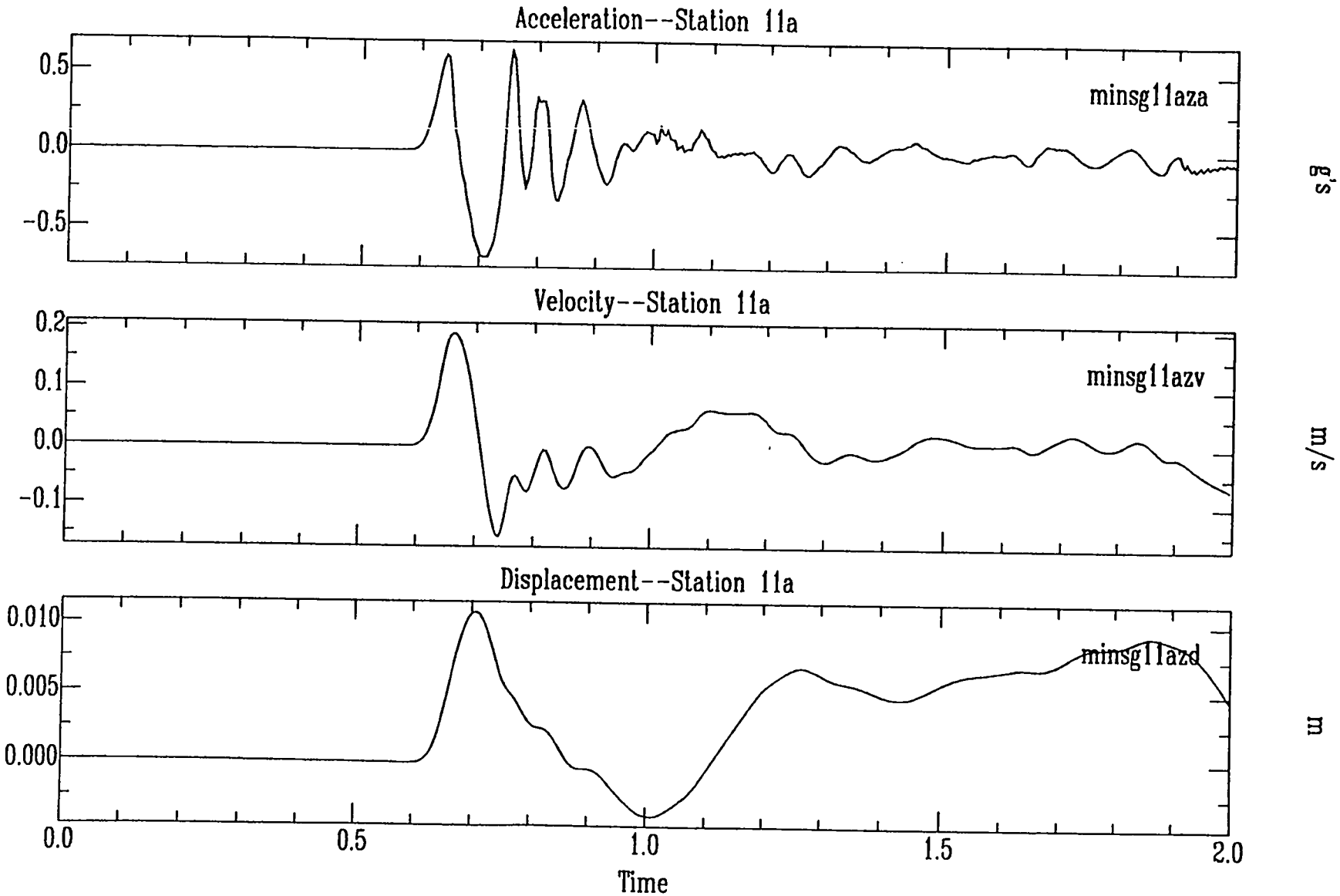


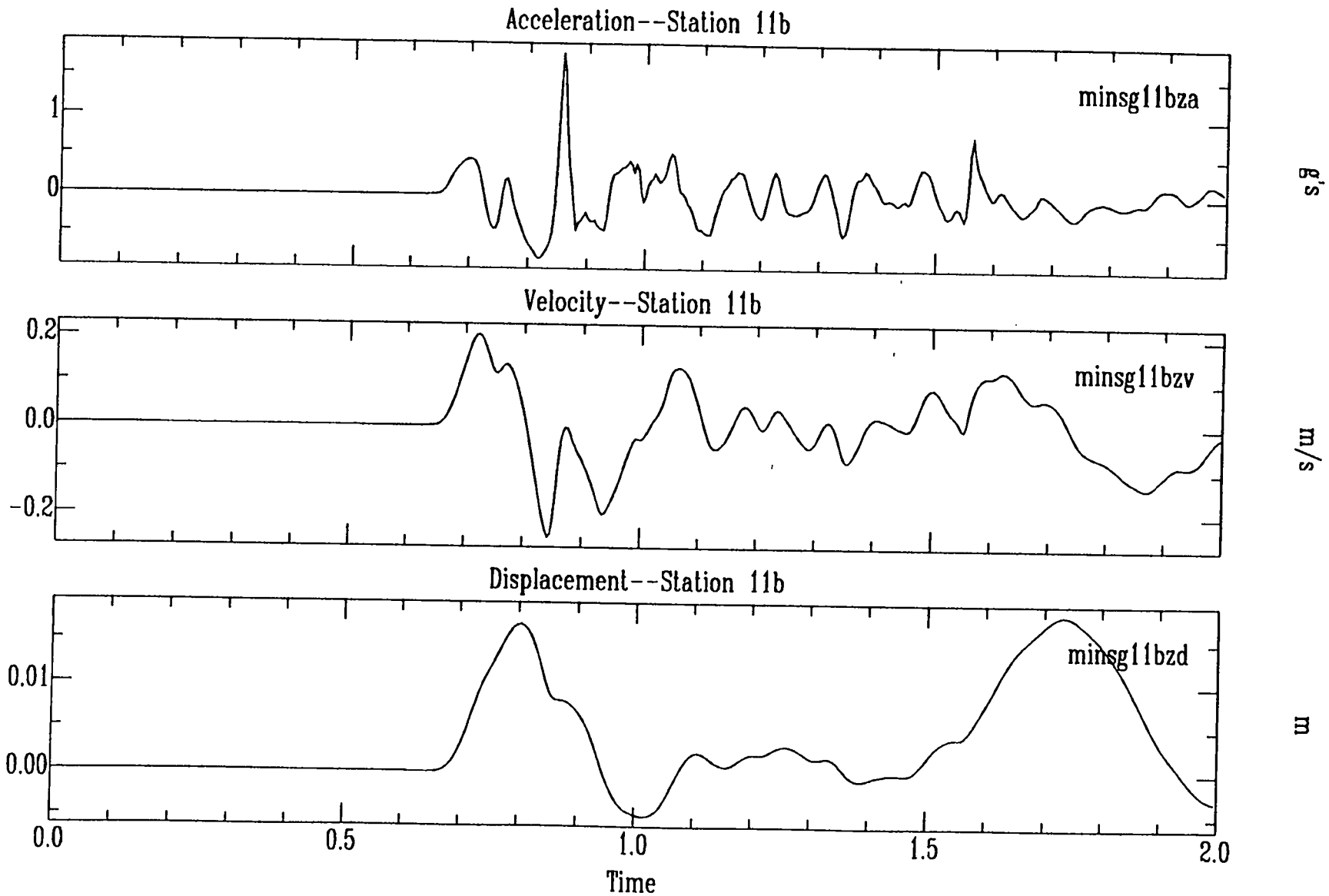
Mineral Quarry Surface Ground Motion



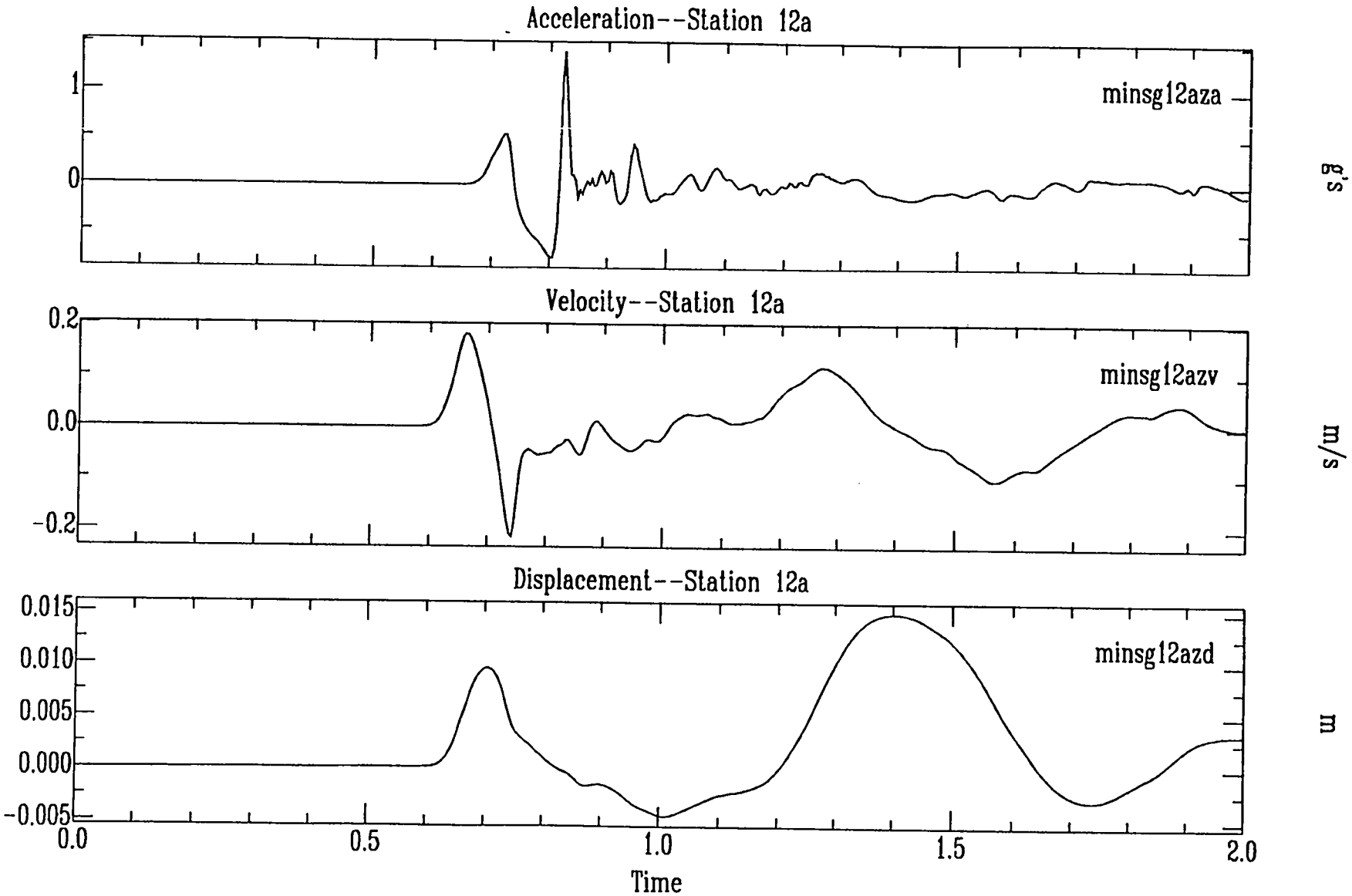
Mineral Quarry Surface Ground Motion



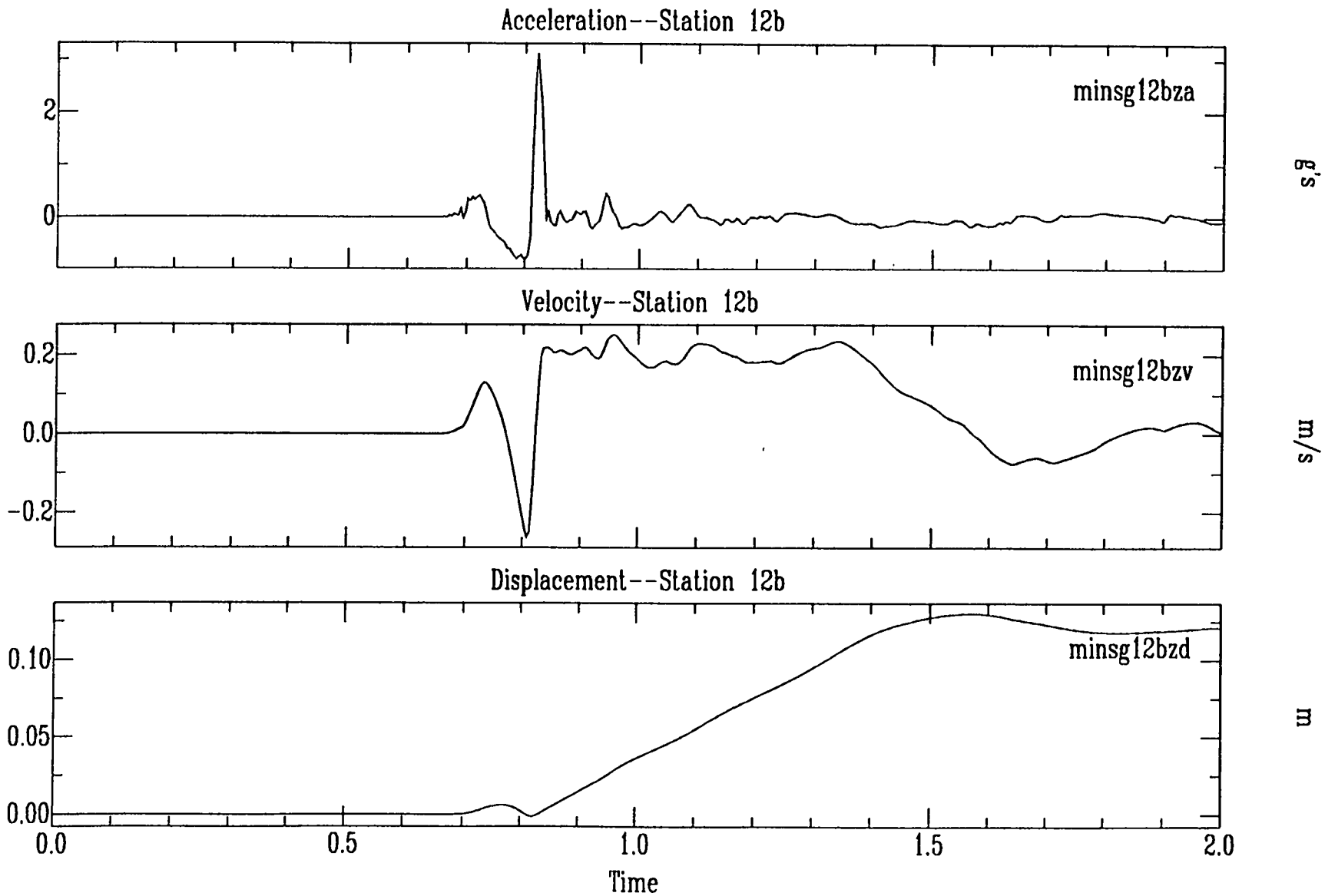
Mineral Quarry Surface Ground Motion



Mineral Quarry Surface Ground Motion



Mineral Quarry Surface Ground Motion



4.9. Bexar (U19ba)

Experiment design. To map the ground motions from a normally buried underground nuclear explosion outside of the spall zone, an extensive set of ground-motion sensors was fielded on Bexar (Table 13 and Fig. 17). In addition to the 15 J-8 stations inside the spall zone (including three near SGZ), 39 ESA stations were fielded using portable digital recorders. These last ranged in distance from just inside the edge of predicted spall (about 1.8 km from SGZ) out to more than 8 km from SGZ.

Results. The J-8 results were originally reported out in April 1991 (Memo J-8-91-073, R. S. Fitzhugh to F. N. App). The following note was included in this memo (italics added):

"* *Data users please note: Because of a RIDS problem, the acceleration data was digitized at a sample rate of only 53 Hz, which probably affected the 'narrow' peak signal amplitudes and the integrated data. Also the baseline offset correction was not operating properly.*"

All of the J-8 stations indicated spall. Of the 39 ESA stations fielded, 31 triggered properly and recorded data. Only three of these functioning ESA stations recorded signals near the spall level (BEXSG12A, 29A, and 32A). These results are shown in the data traces in Fig. 18 (43 pages).

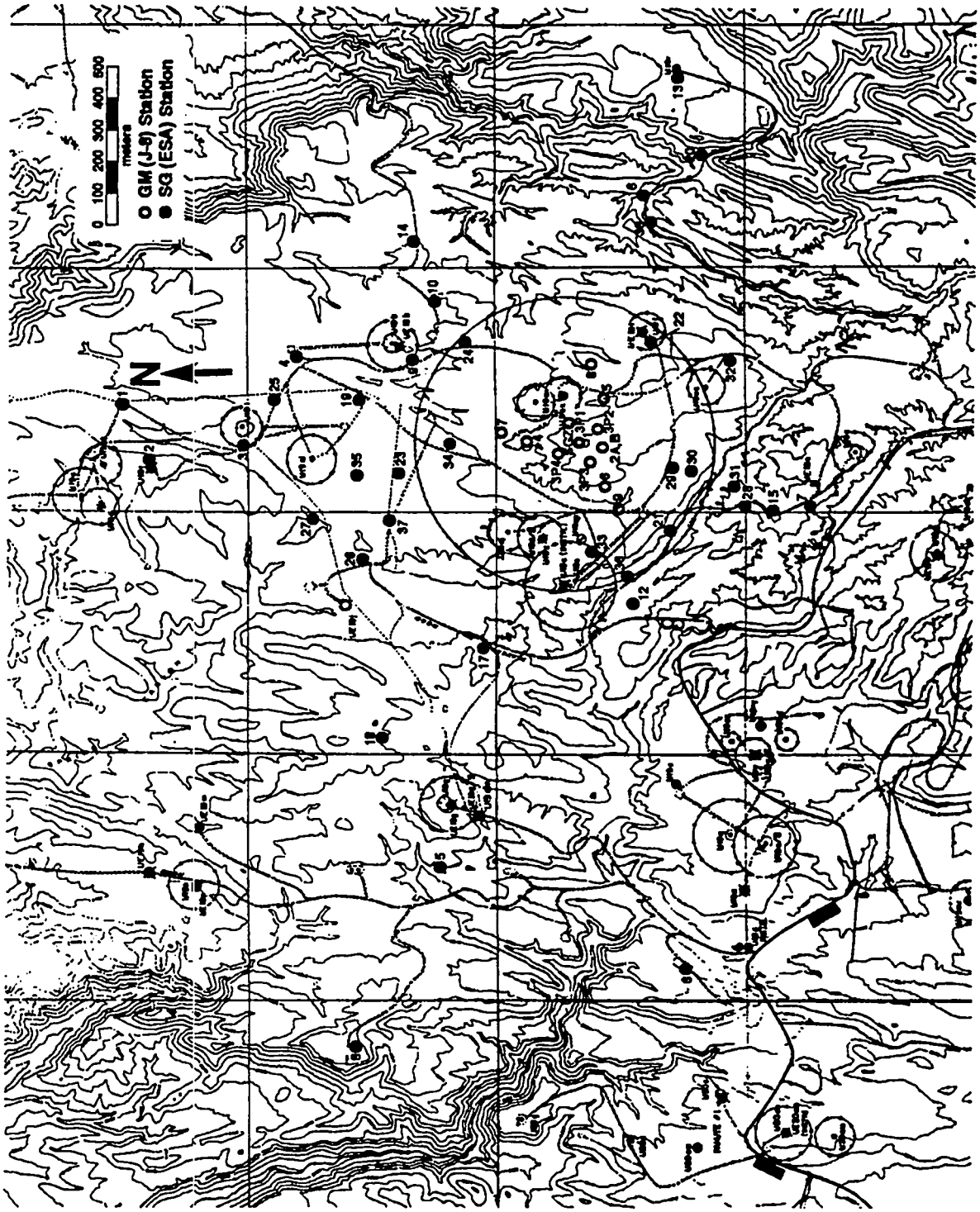


Fig. 17. Bexar station map.

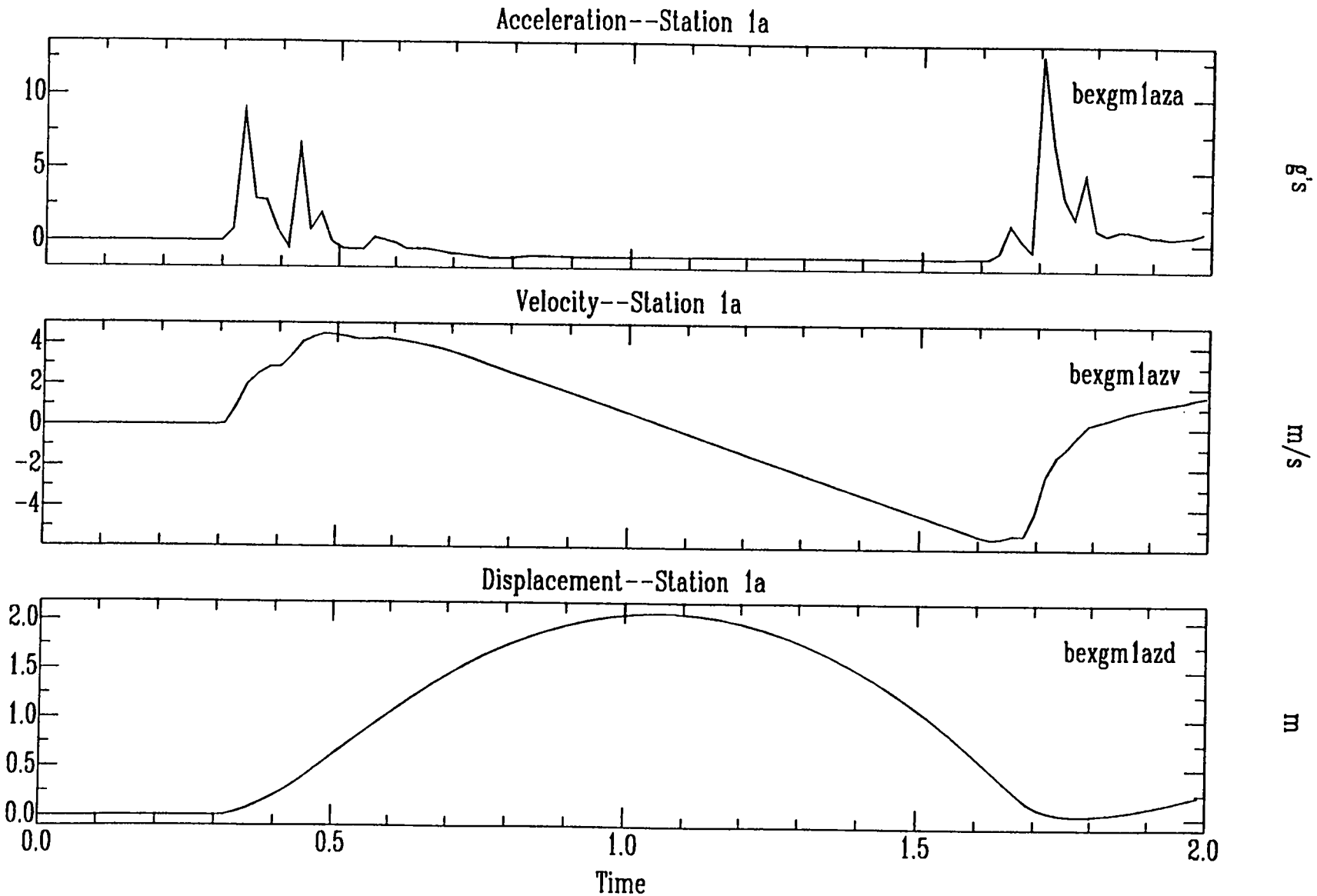
Table 13. Bexar Station Data

Station Name	Location	Accelerometer	Northing (m) 282534	Easting(m) 183764	Slant Range 629 (m) DOB	Travel Time
BEXGM1A	15 m S08W	Endevco 25 g	282519	183762	629	0.29
BEXGM1B	15 m S08W	Endevco 25 g	282519	183762	629	0.29
BEXGM1C	15 m S08W	Endevco 25 g	282519	183762	629	0.29
BEXGM2A	258 m S30W	Endevco 25 g	282311	183635	680	0.315
BEXGM2B	258 m S30W	Endevco 25 g	282311	183635	680	0.315
BEXGM3P1	258 m N60E	Endevco 25 g	282663	183987	680	0.31
BEXGM3P2	258 m S30E	Endevco 25 g	282311	183893	680	0.31
BEXGM3P3	258 m S60W	Endevco 25 g	282405	183541	680	0.32
BEXGM3P4	258 m N32W	Endevco 25 g	282753	183628	680	0.295
BEXGM4A	640 m N	Endevco 20 g	283174	183764	897	0.39
BEXGM5A	640 m S60E	Endevco 20 g	282215	184318	897	0.42
BEXGM6A	640 m S60W	Endevco 20 g	282214	183210	897	0.42
BEXGM7A	977 m N04E	Endevco 20 g	283509	183831	1162	0.48
BEXGM8A	968 m S79E	Endevco 20 g	282356	184716	1155	0.55
BEXGM9A	915 m S60W	Endevco 20 g	282075	182974	1109	0.47
BEXSG1A	5510 m N04E	Terra Tec 5.28 g	288020	184126	5534	5.221
BEXSG2A	2930 m N35.1W	Terra Tec 5.28 g	284927	182072	2997	5.338
BEXSG3A	4130 m N1.5W	Terra Tec 5.28 g	286630	183643	4146	5.248
BEXSG4A	3440 m N16.5E	Terra Tec 5.28 g	285847	184728	3507	5.133
BEXSG5A	5640 m N73.2W	Terra Tec 5.28 g	282929	178613	5204	5.286
BEXSG6A	6810 m S78W	Terra Tec 5.28 g	281094	177112	6835	5.157
BEXSG7A	2960 m S15.6W	Terra Tec 5.28 g	279681	182978	3025	5.219
BEXSG9A	2190 m N26.9E	Terra Tec 5.28 g	284504	184751	2291	5.097
BEXSG11A	2520 m S60.7W	Terra Tec 3.7 g	281296	181571	2596	5.246
BEXSG11B	2700 m S57.5W	Terra Tec 3.7 g	281075	181492	2772	5.243
BEXSG12A	2210 m S68.5W	Terra Tec 3.7 g	281719	181712	2296	5.062
BEXSG13A	4870 m S74.1E	Terra Tec 3.7 g	281223	188452	4908	5.139
BEXSG14A	3100 m N51.8E	Terra Tec 3.7 g	284466	186196	3169	5.214
BEXSG15A	2650 m S22.7W	Terra Tec 3.7 g	280091	182754	2717	5.074
BEXSG16A	3180 m S72.1E	Terra Tec 3.7 g	281572	186792	3239	5.334
BEXSG17A	2900 m N68.2W	Terra Tec 3.7 g	283603	181067	2969	5.209
BEXSG18A	4460 m N57.8W	Terra Tec 3.7 g	284898	179981	4505	5.259
BEXSG19A	2690 m N9.1E	Terra Tec 3.7 g	285190	184182	2761	5.052

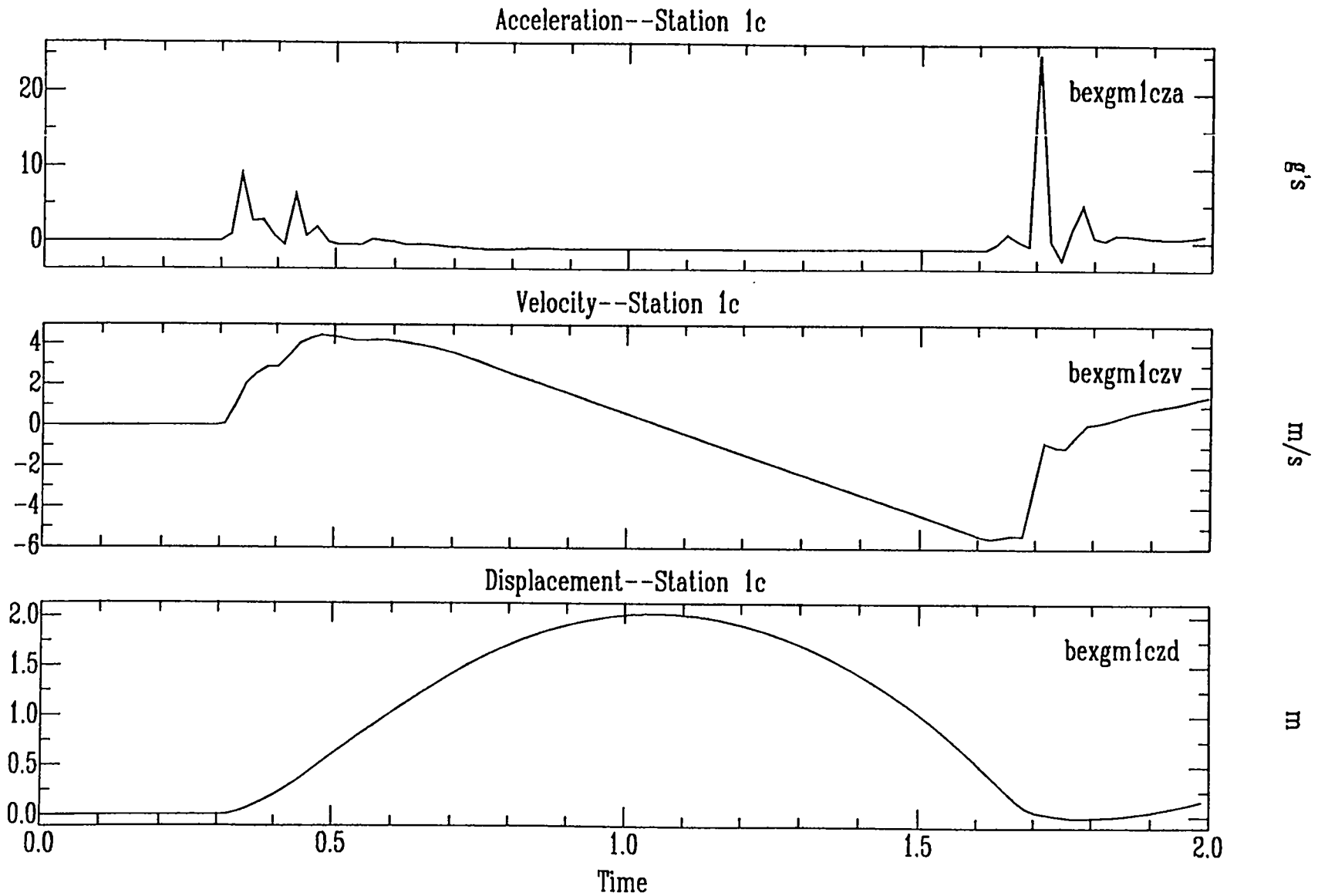
Table 13. Bexar Station Data (Concluded)

Station Name	Location	Accelerometer	Northing (m) 282534	Easting(m) 183764	Slant Range 629 (m) DOB	Travel Time
BEXSG20A	3840 m S65.2E	Terra Tec 3.7 g	280941	187256	3889	4.697
BEXSG21A	1710 m S40.7W	Endevco	281234	182653	1822	3.305
BEXSG22A	1570 m S51.1E	Endevco	281626	185040	1688	6.166
BEXSG23A	2180 m N12.7W	Endevco	284665	183279	2274	3.483
BEXSG24A	1670 m N43.1E	Endevco	283739	184904	1774	8.514
BEXSG25A	3640 m N6.8E	Endevco	286145	184178	3689	8.953
BEXSG26A	2930 m N30.6W	TerraTec 3.7g	285050	182268	2994	3.699
BEXSG26B	2930 m N30.6W	Endevco	285050	182268	2994	3.675
BEXSG27A	3330 m N17.8W	Endevco	85562	182700	3271	8.721
BEXSG29A	1290 m S20.5W	Endevco	281314	183318	1443	9.922
BEXSG32A	2060 m S25.8E	Endevco	280653	184659	2176	9.788
BEXSG37A	2550 m N25.6W	Endevco	284829	182657	2625	9.242

Bexar Surface Ground Motion



Bexar Surface Ground Motion



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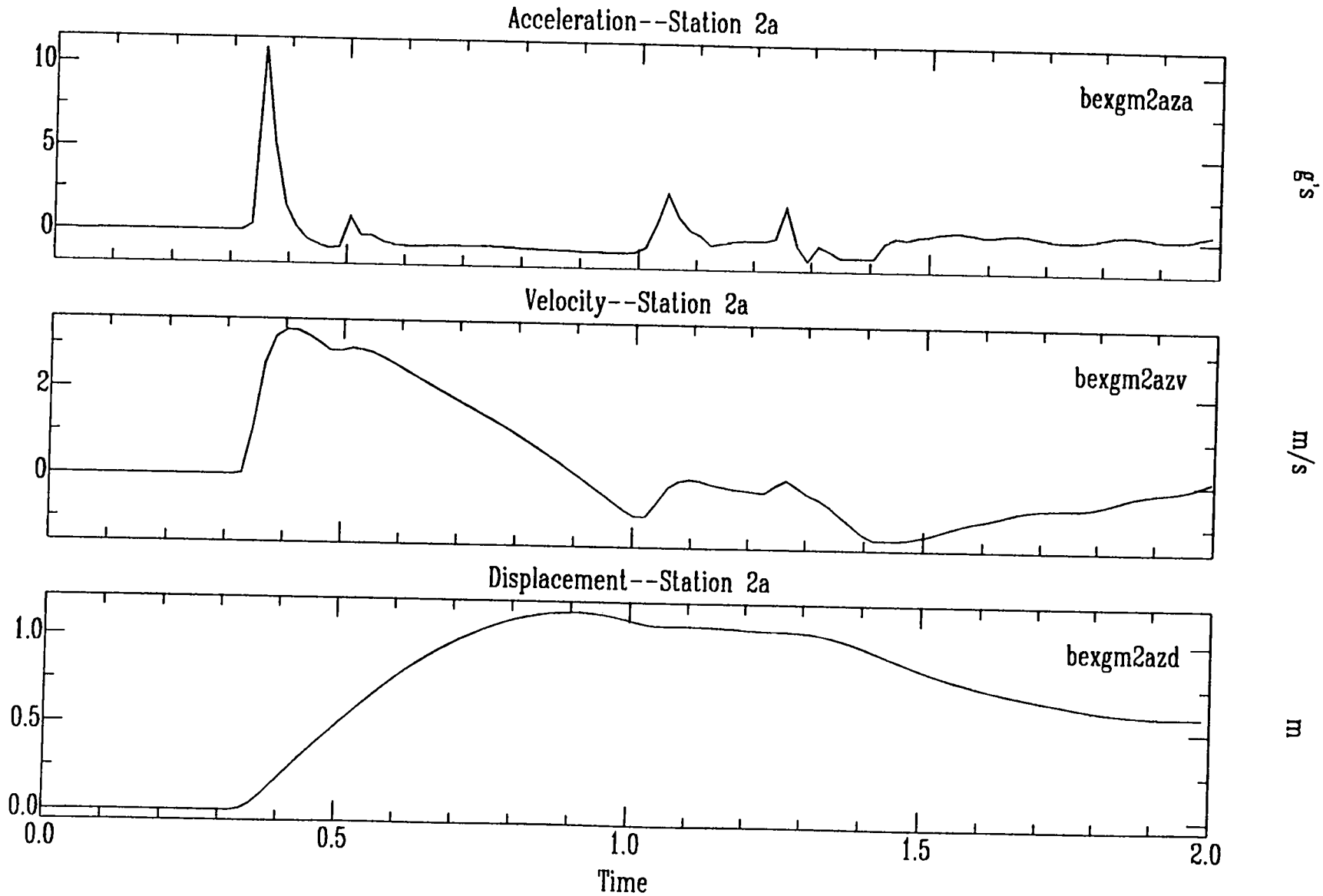

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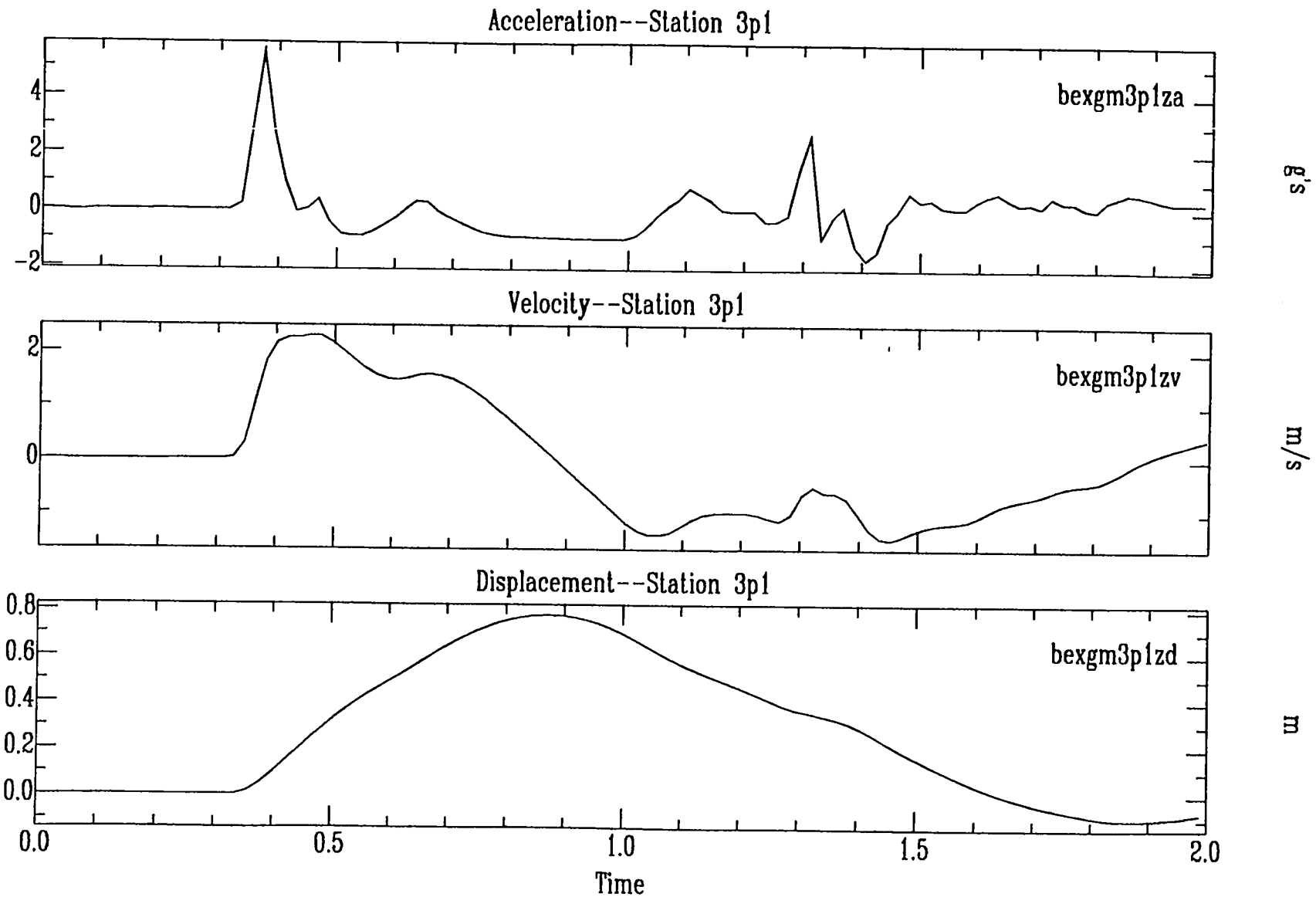

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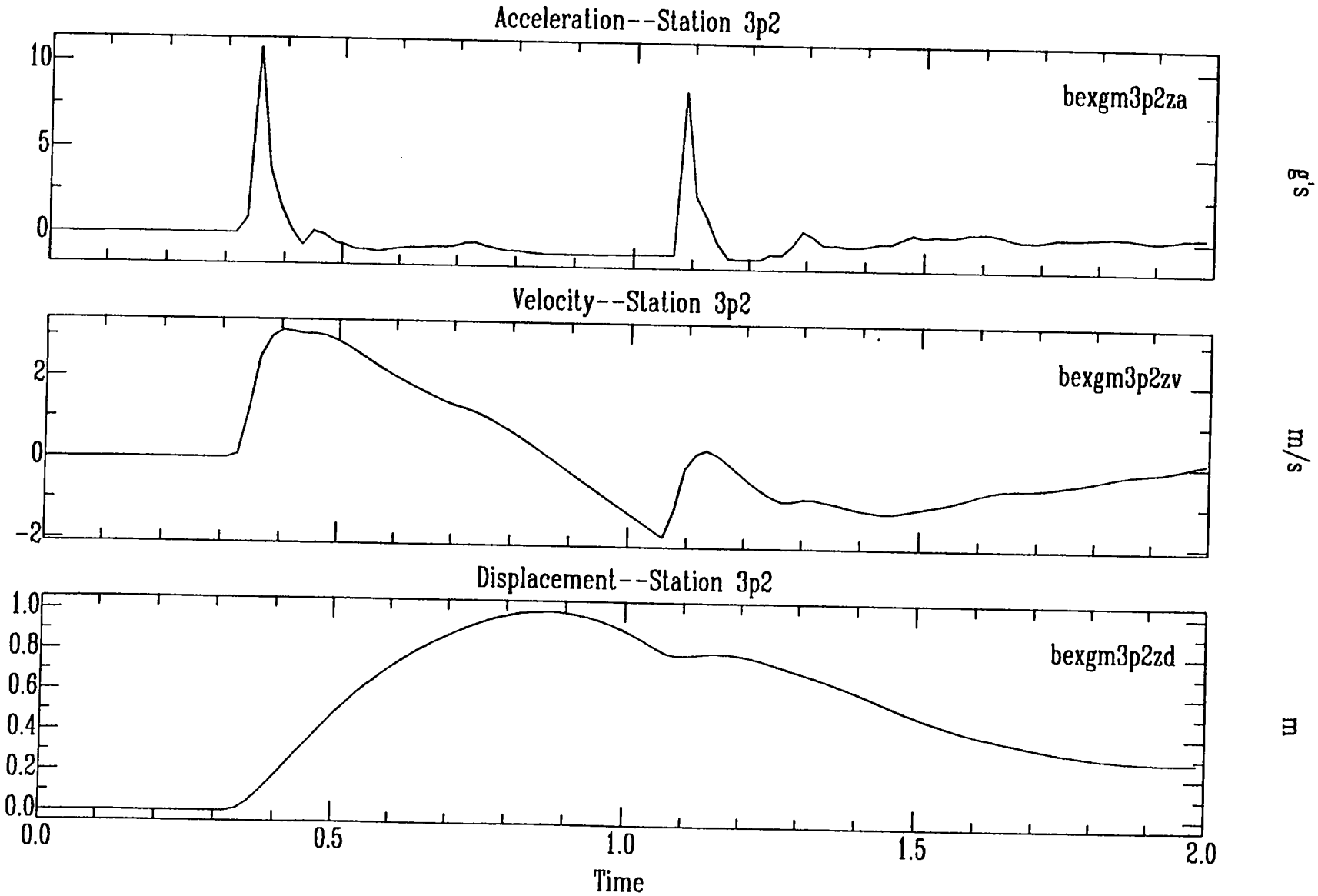

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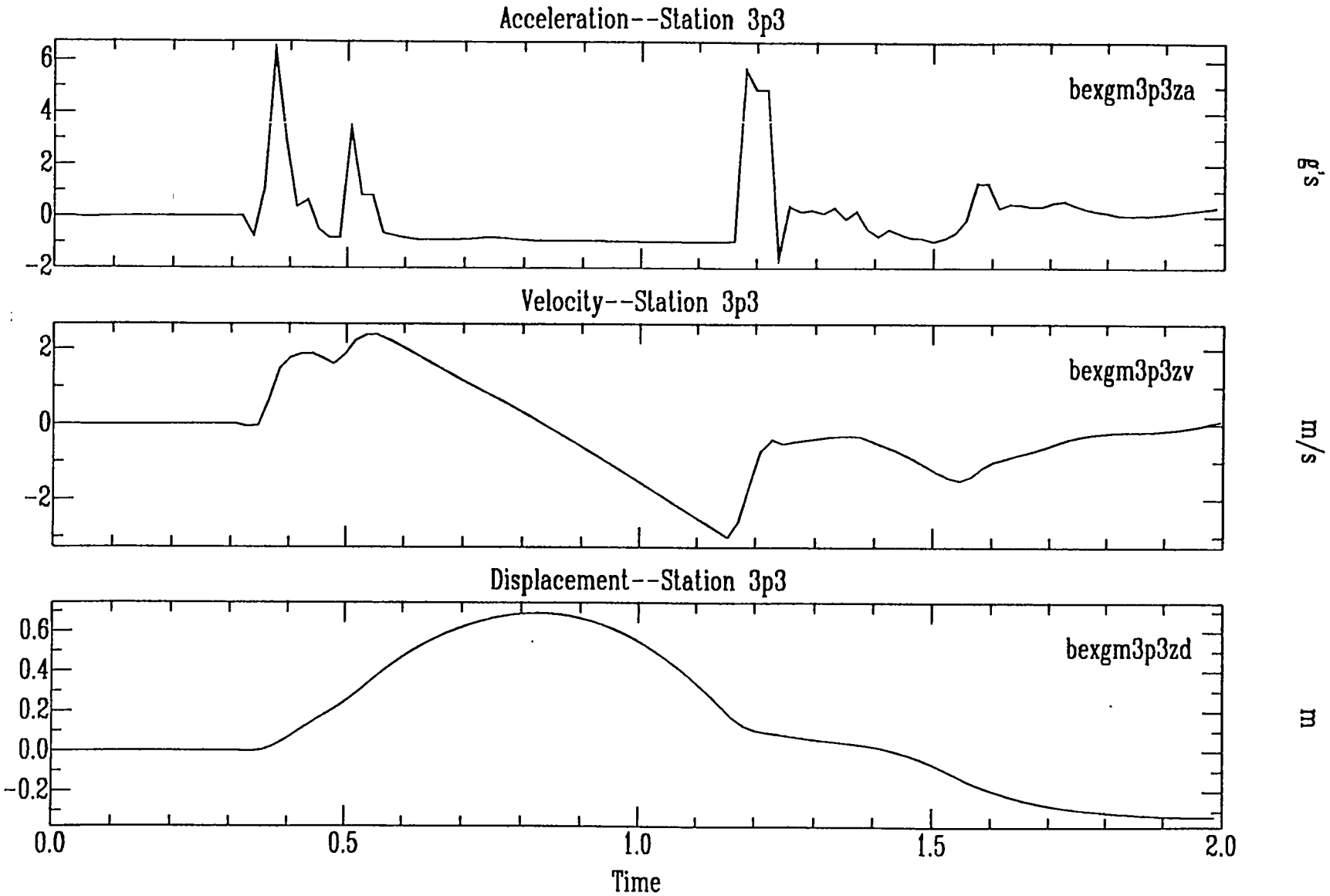

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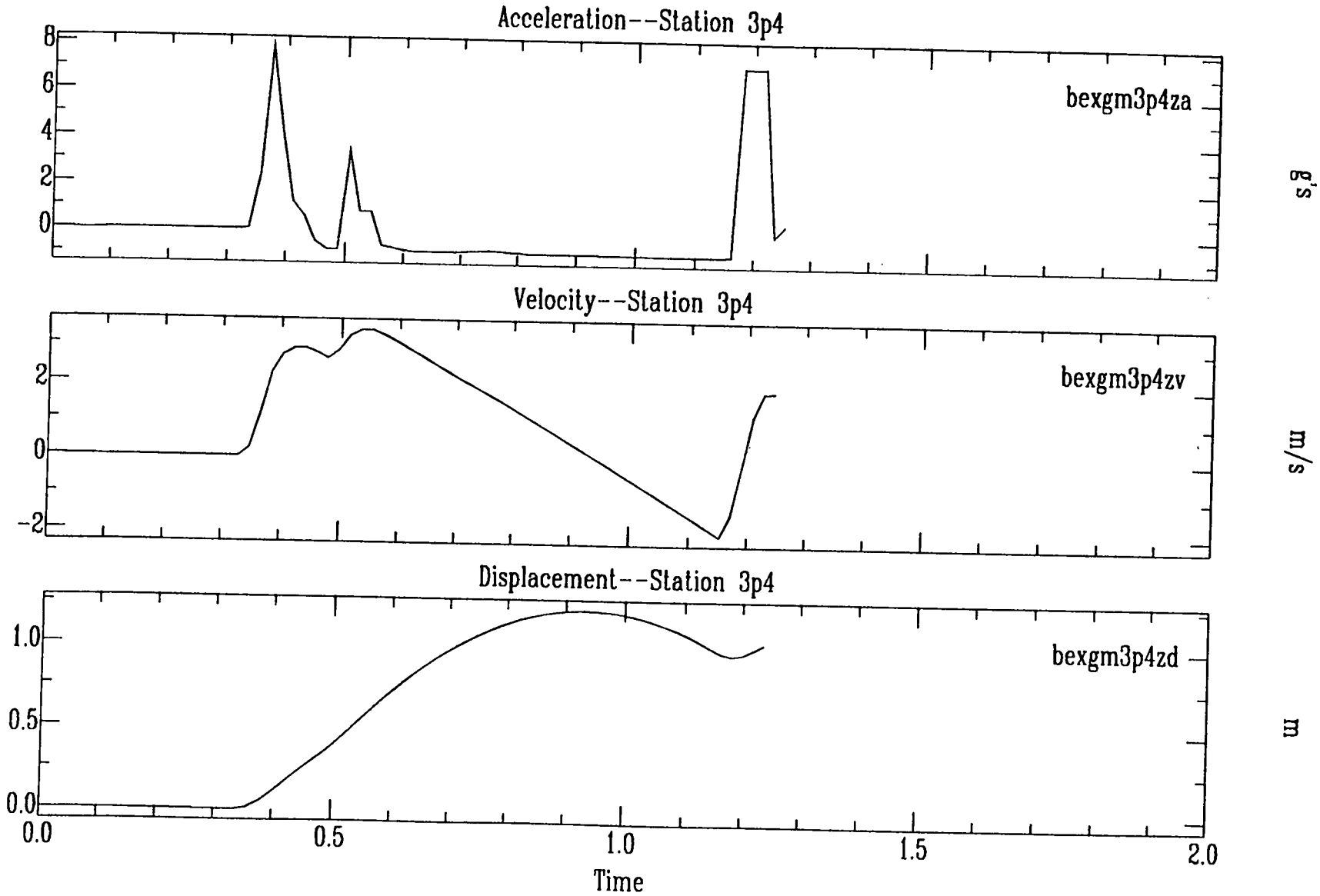

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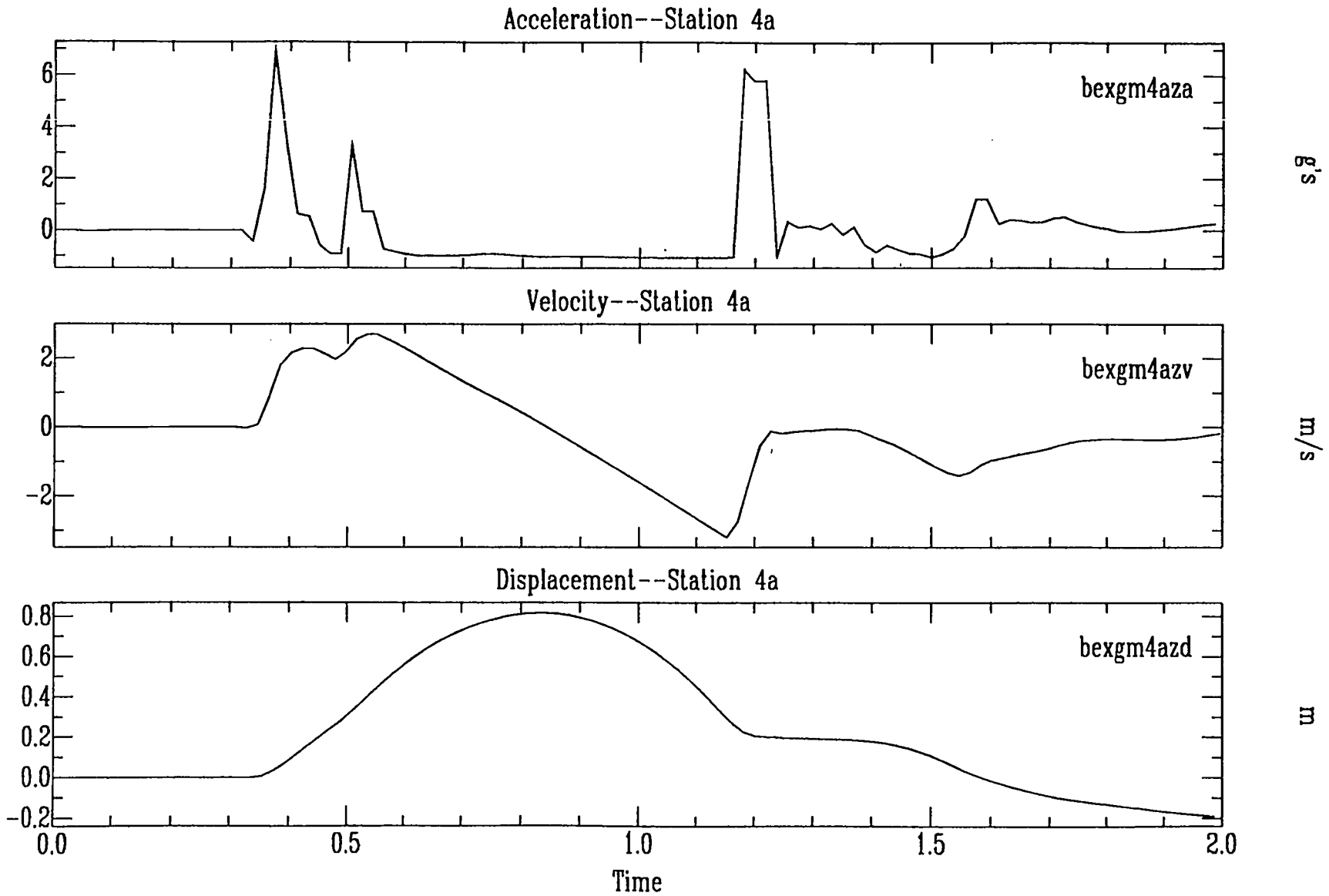

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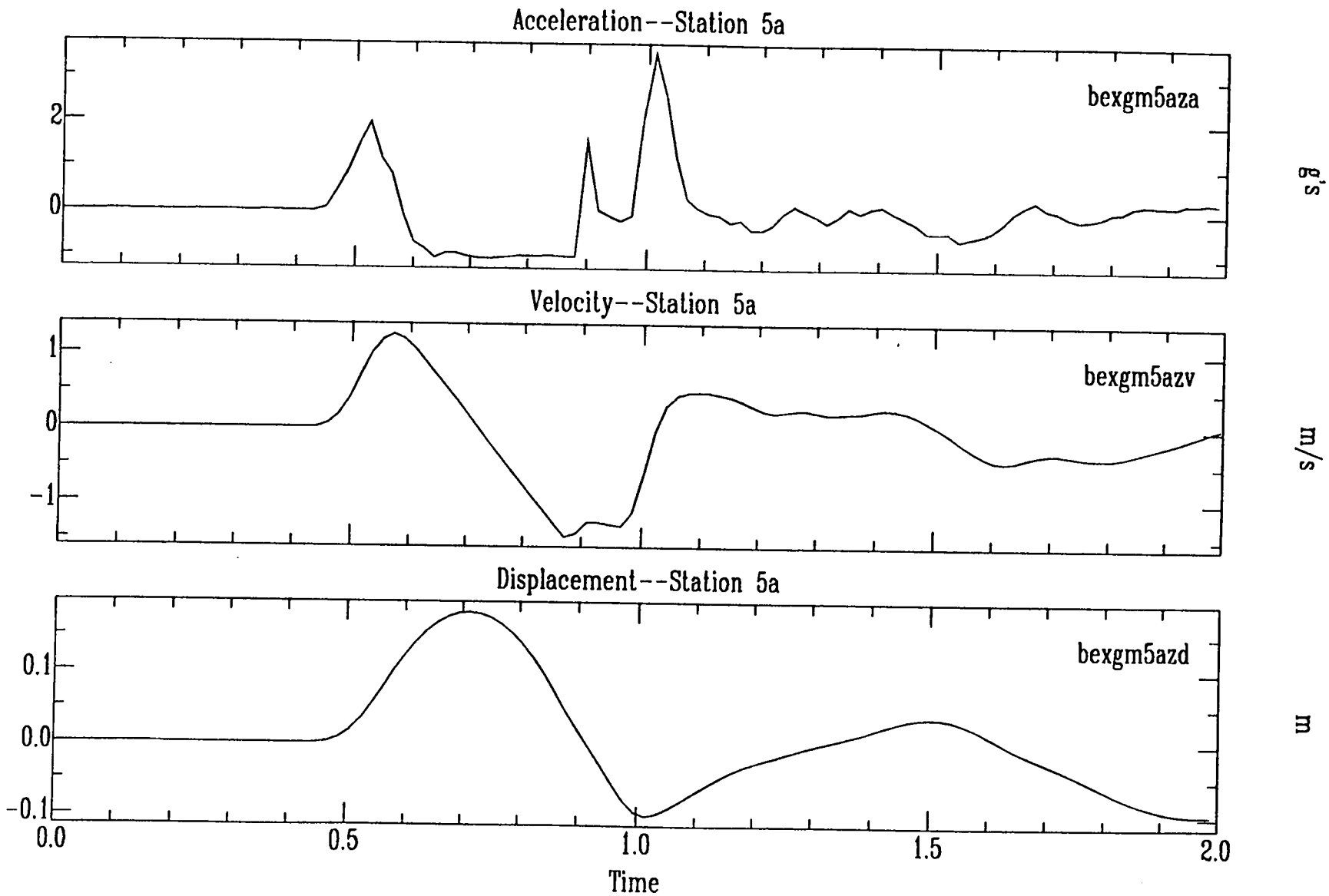

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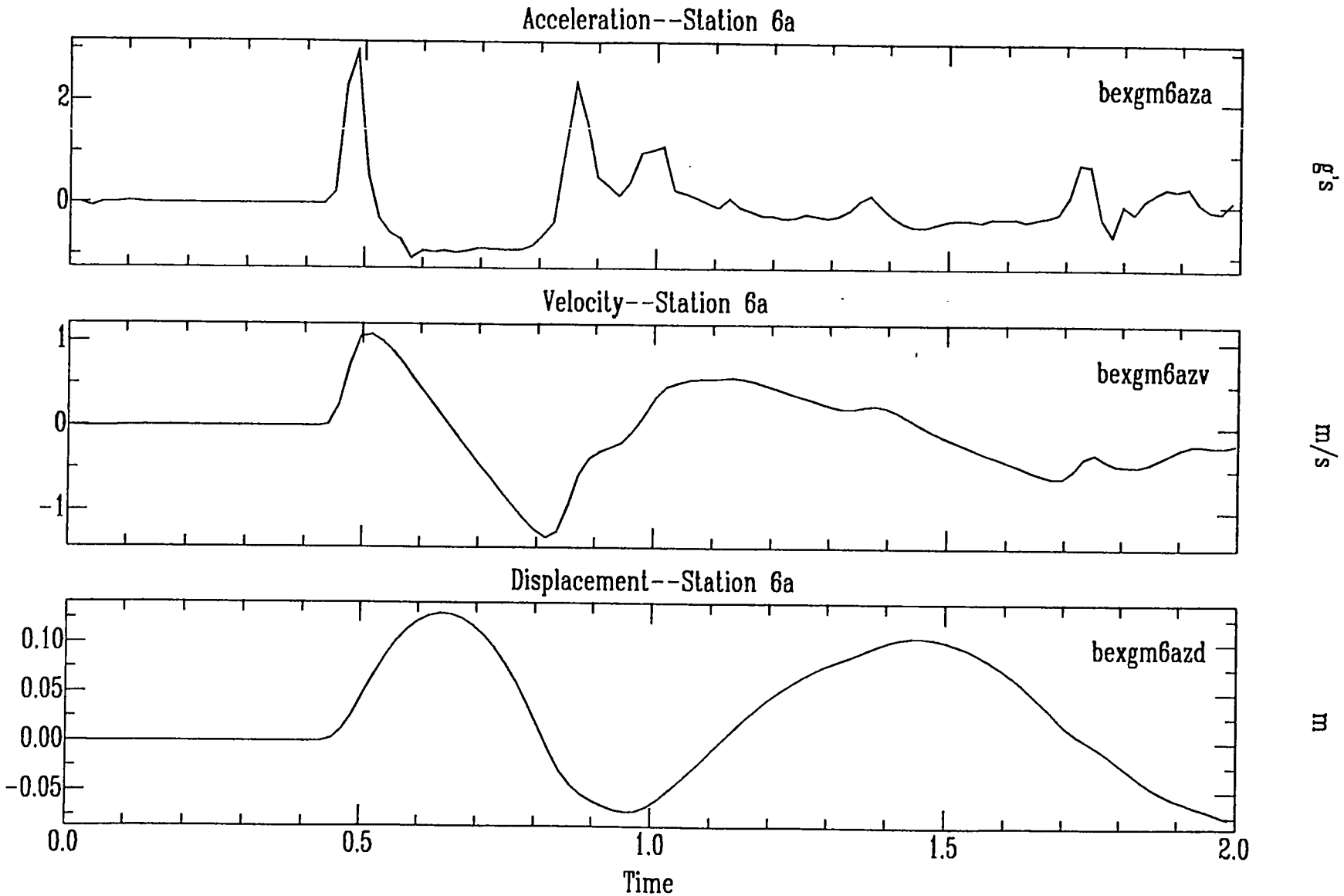

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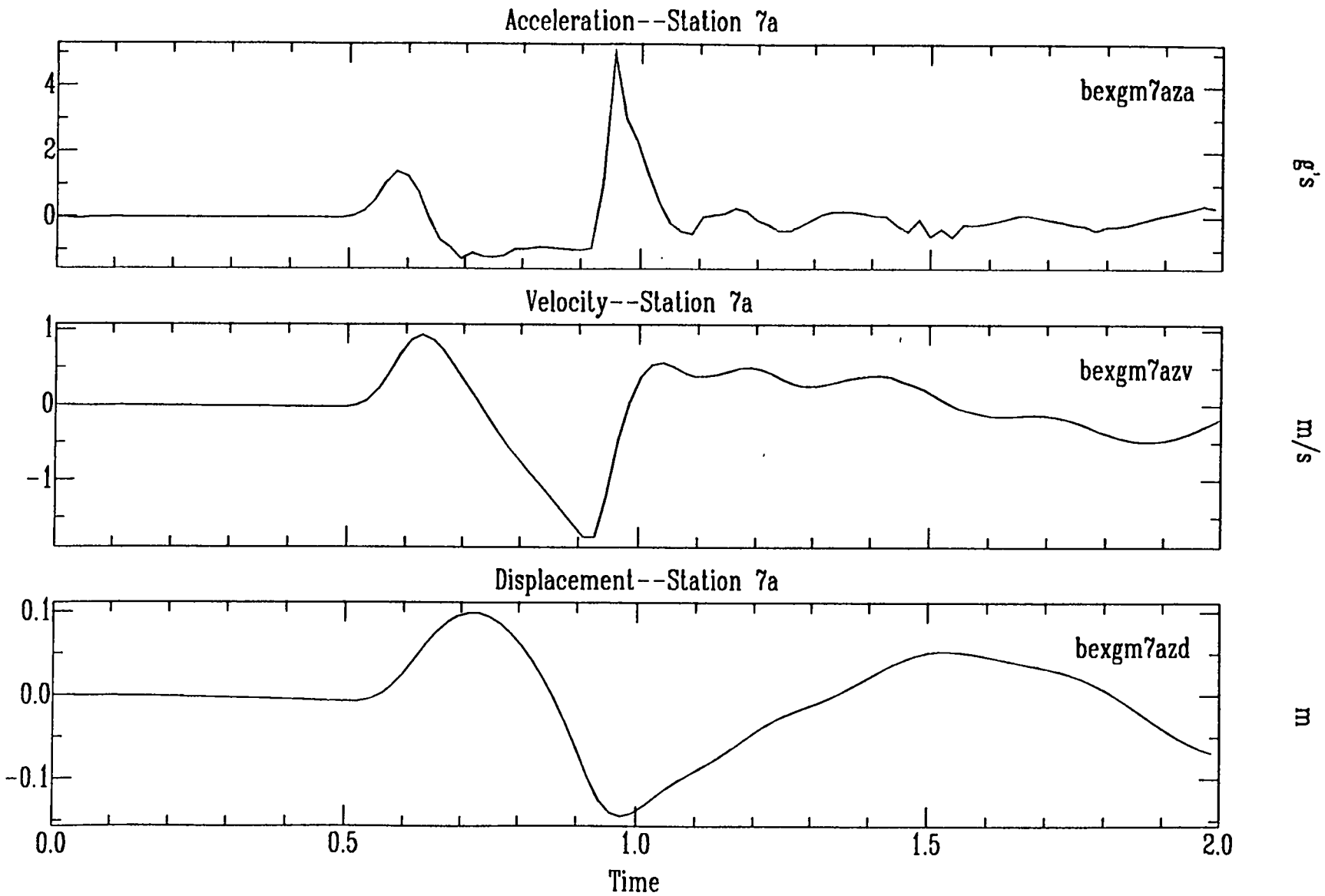

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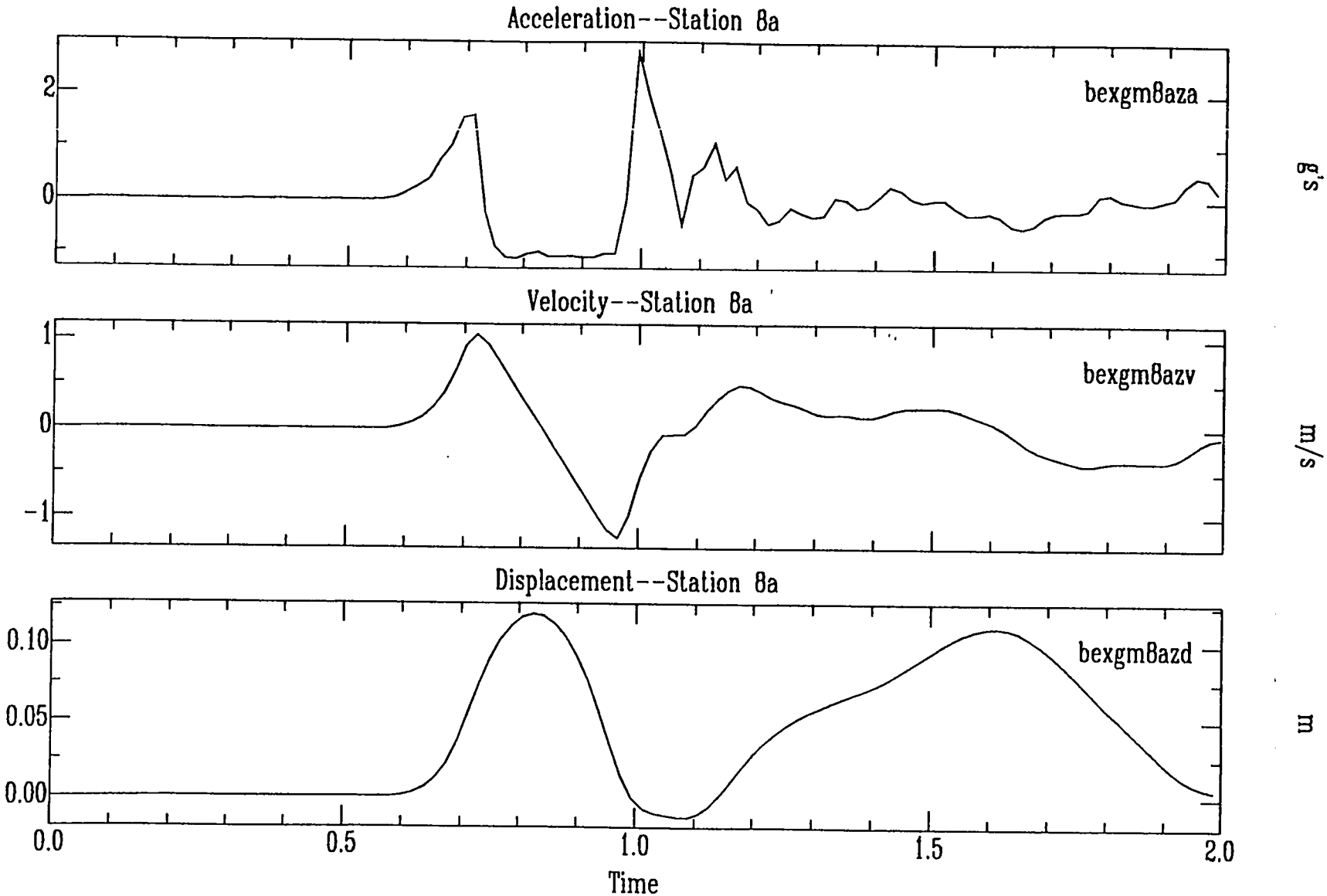

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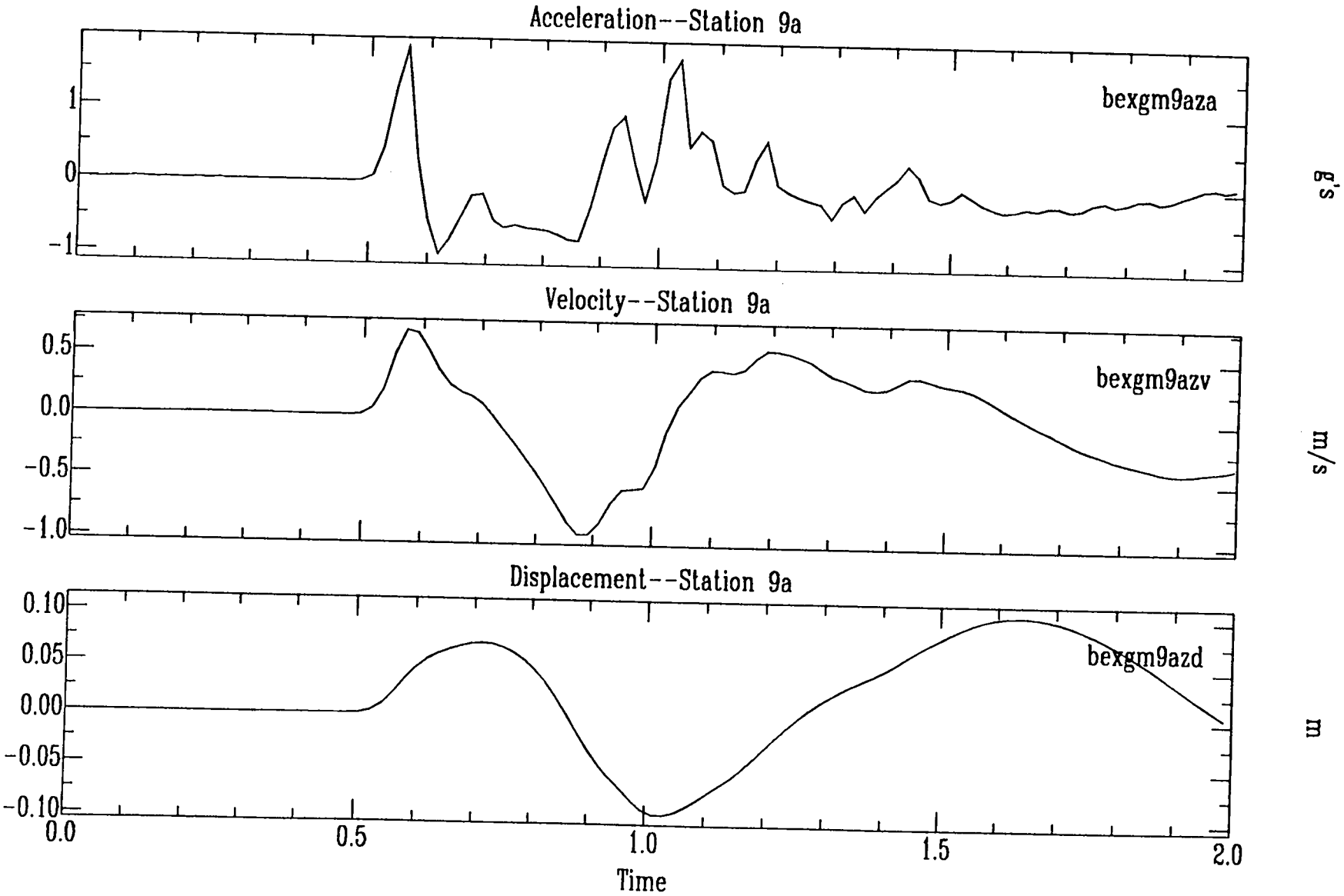

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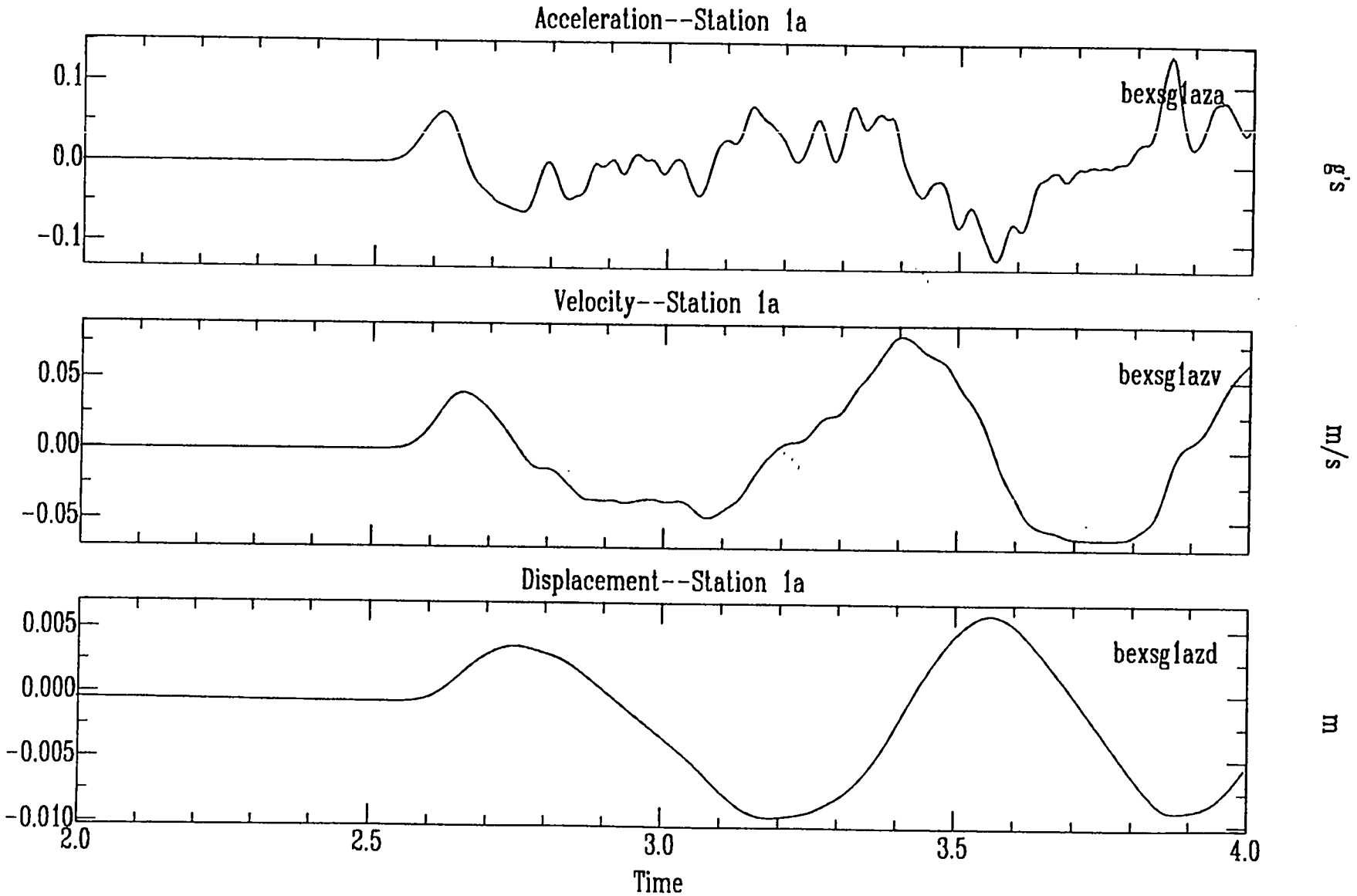

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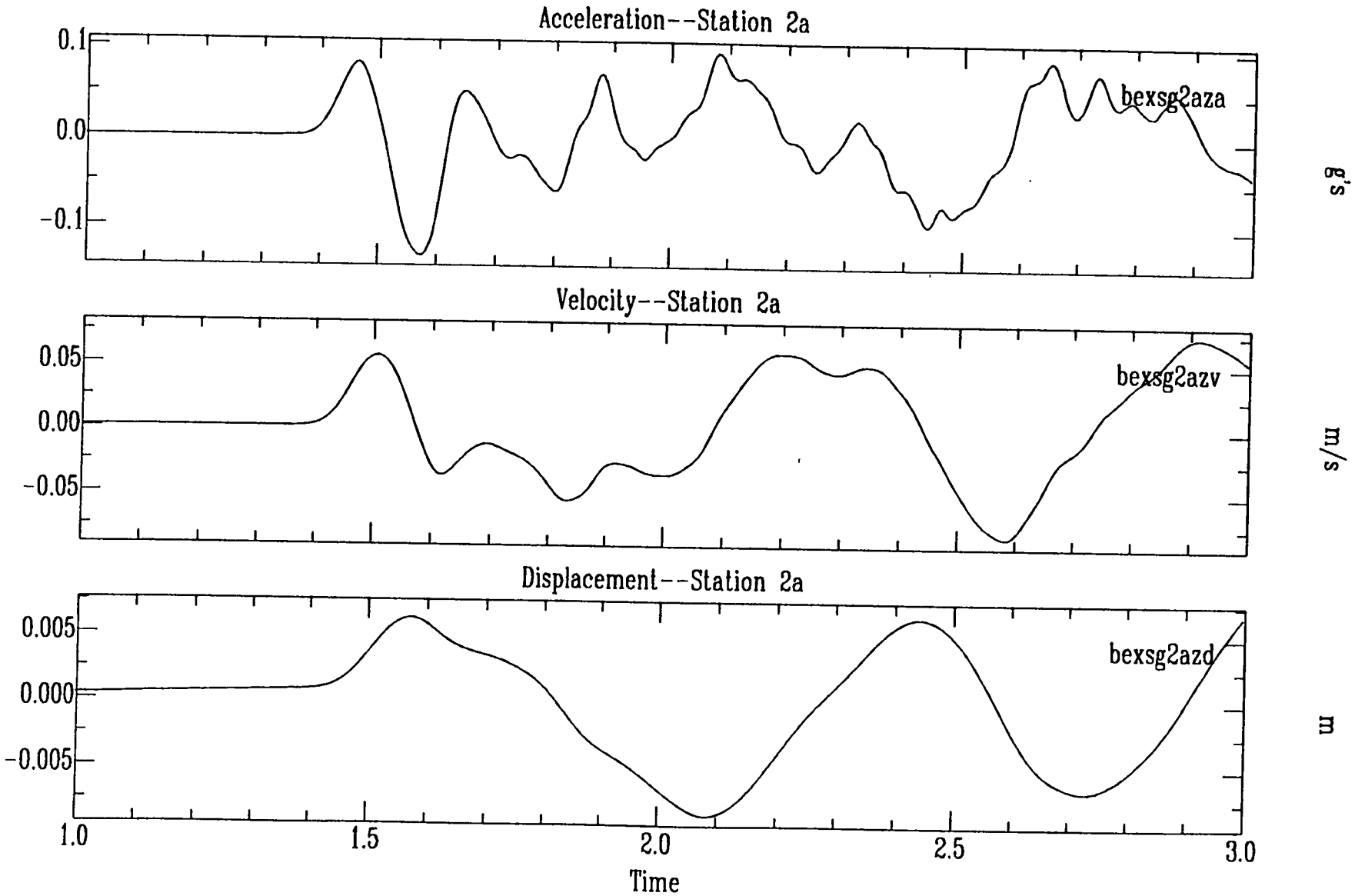

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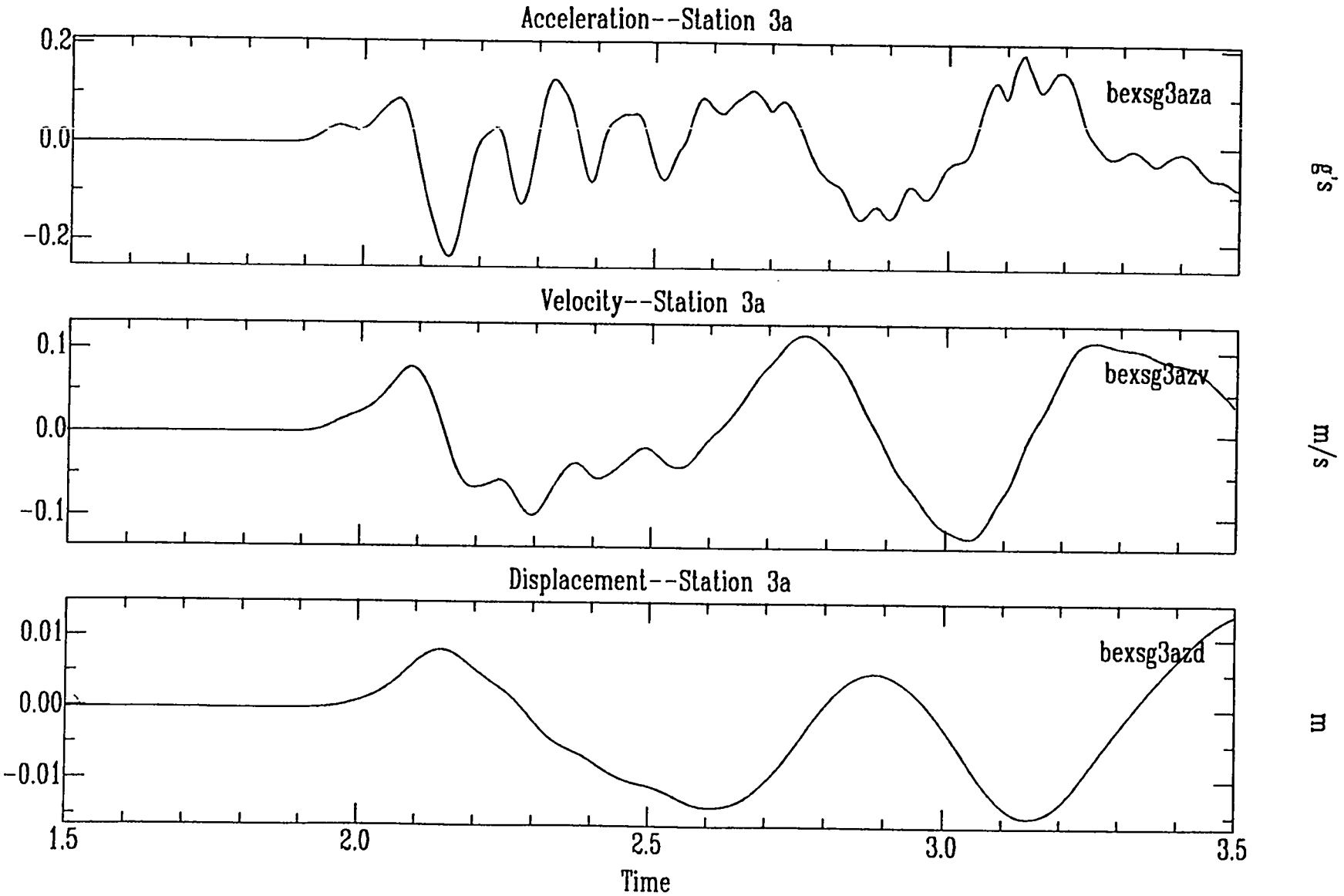

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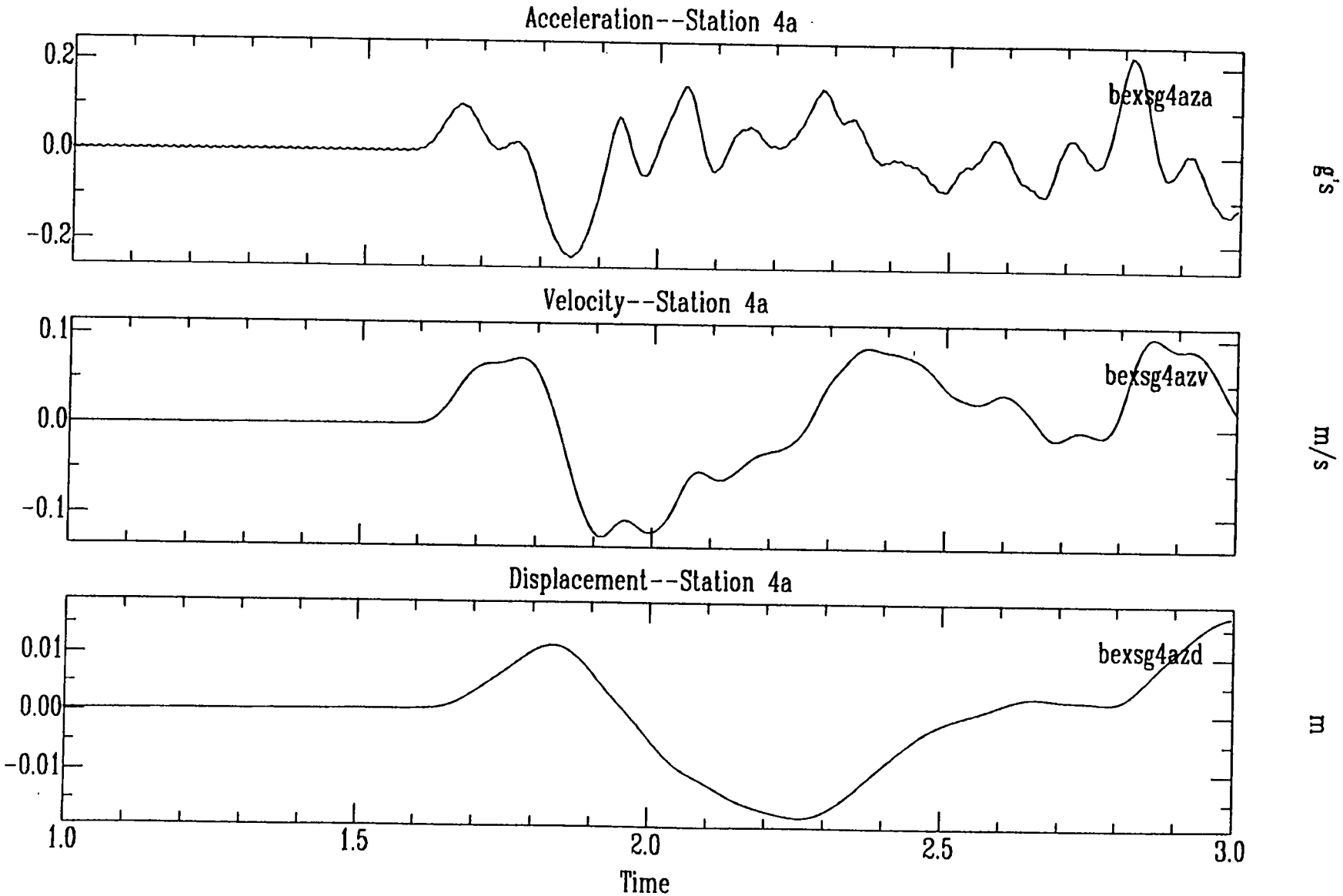

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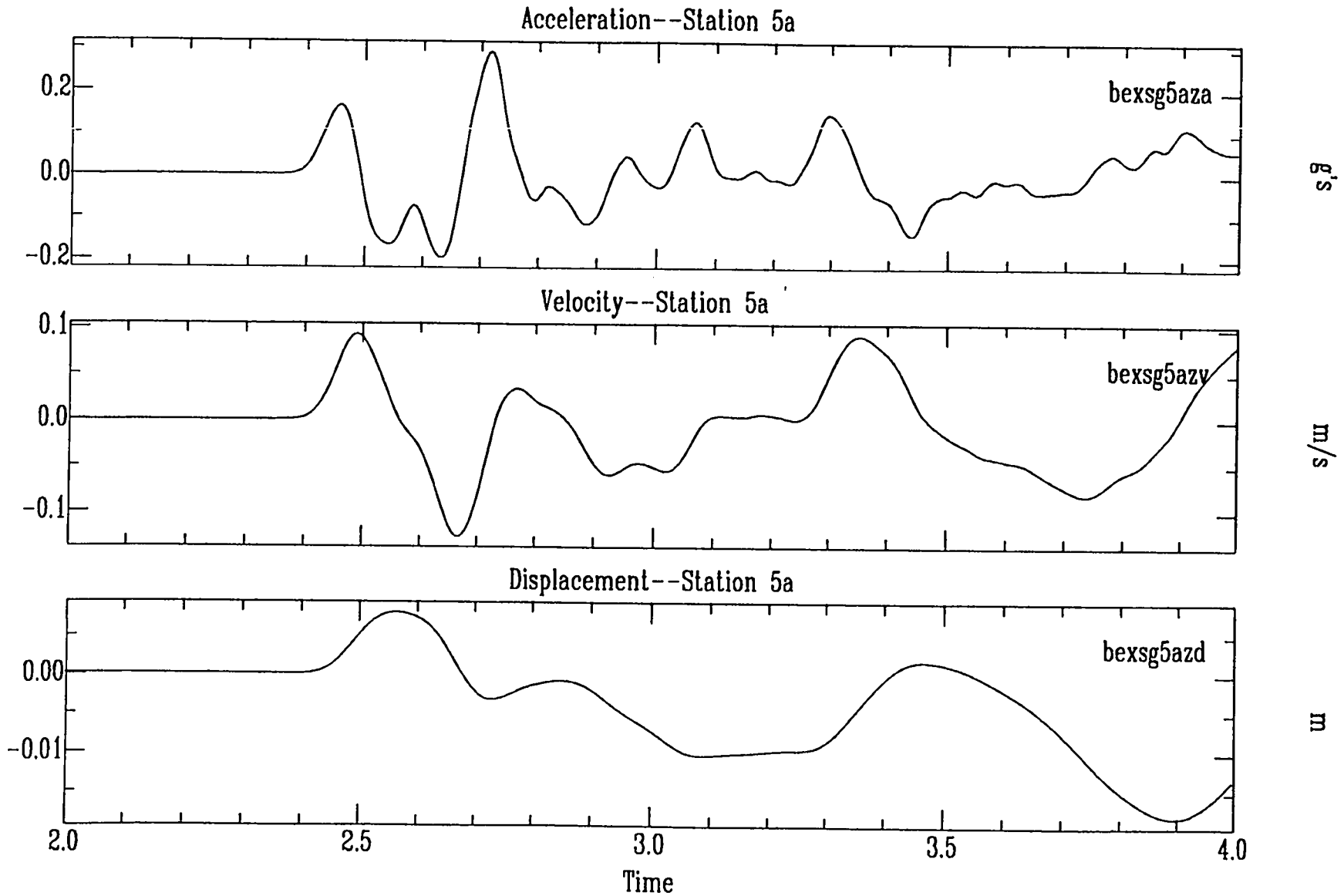

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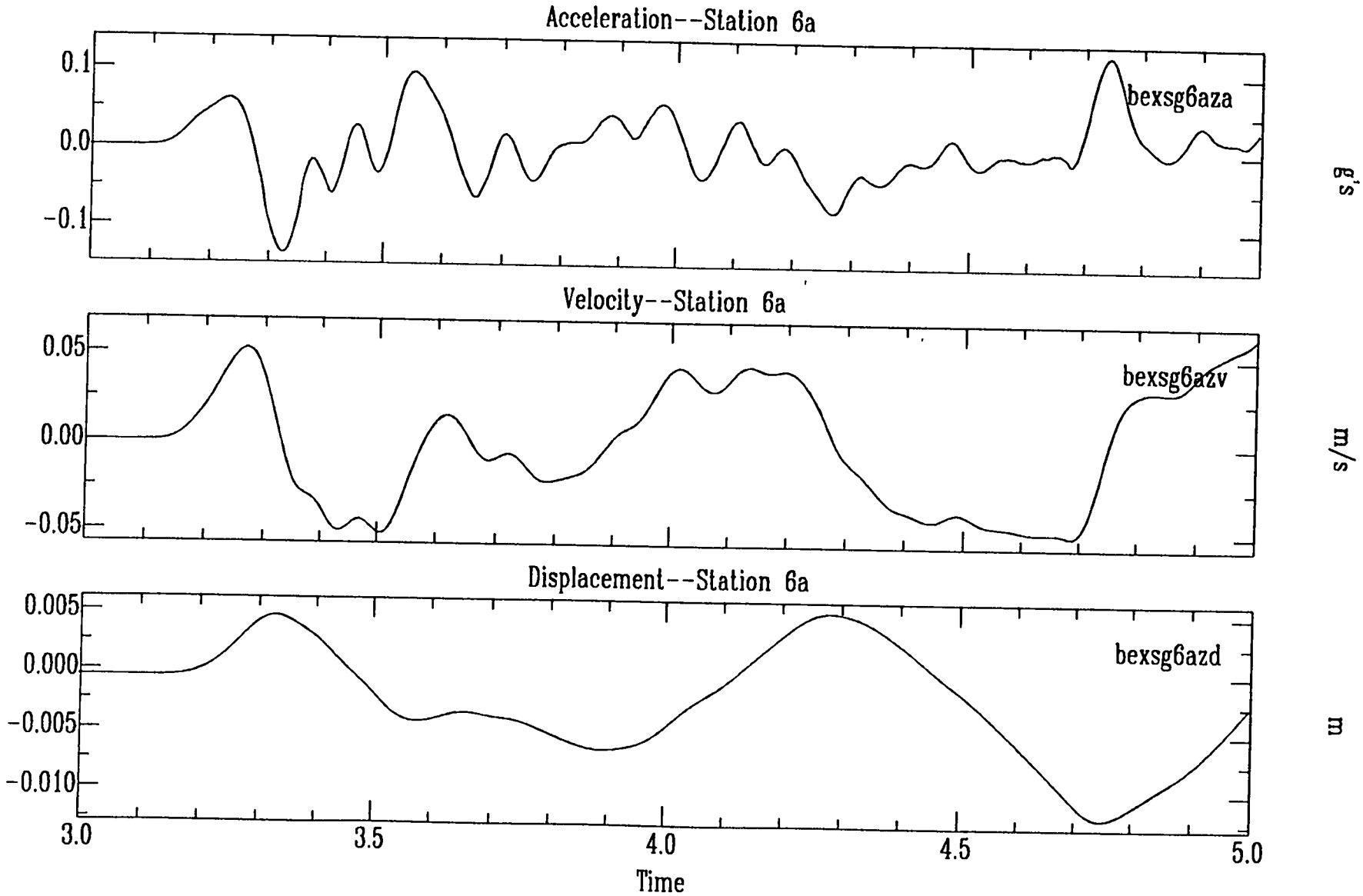

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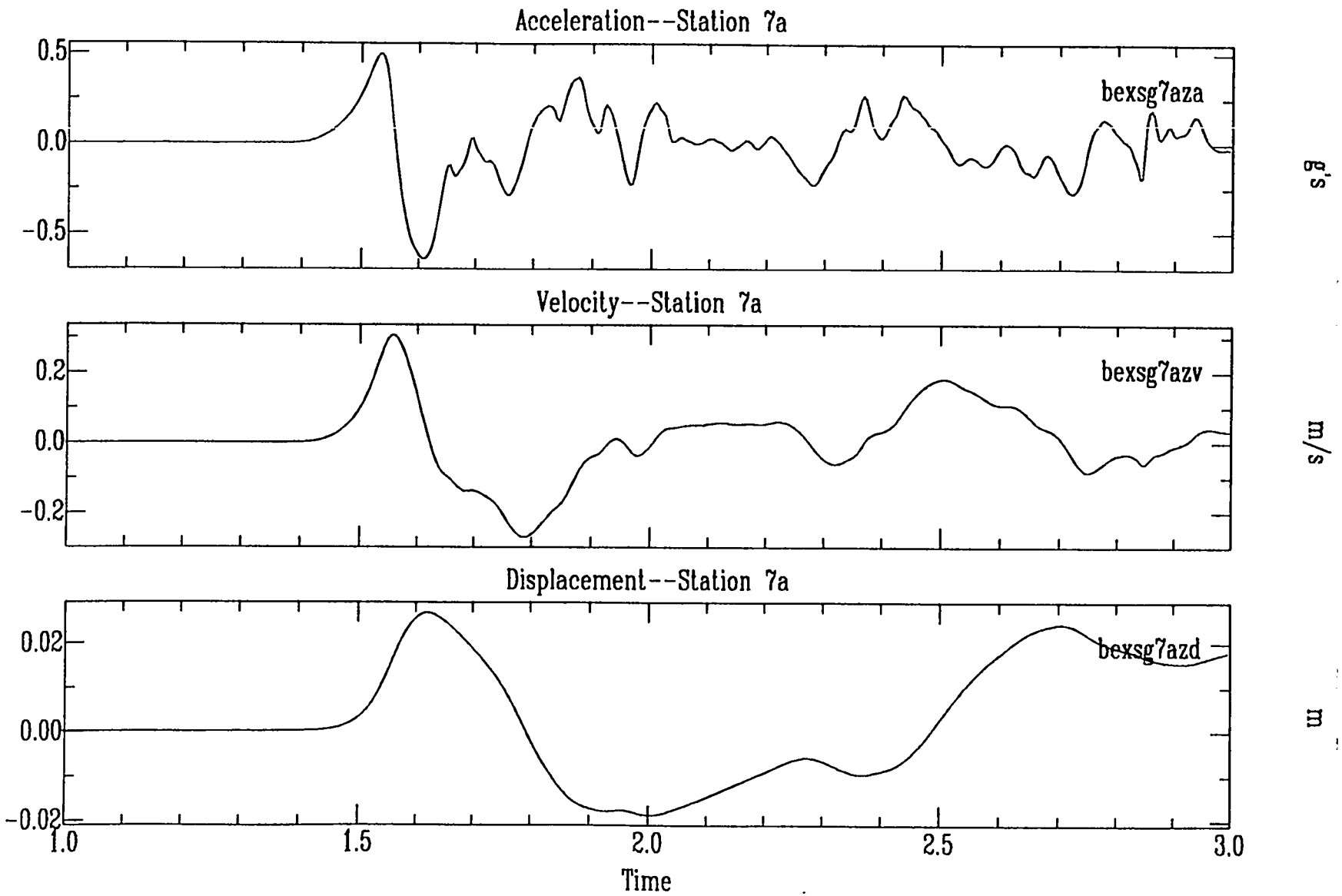

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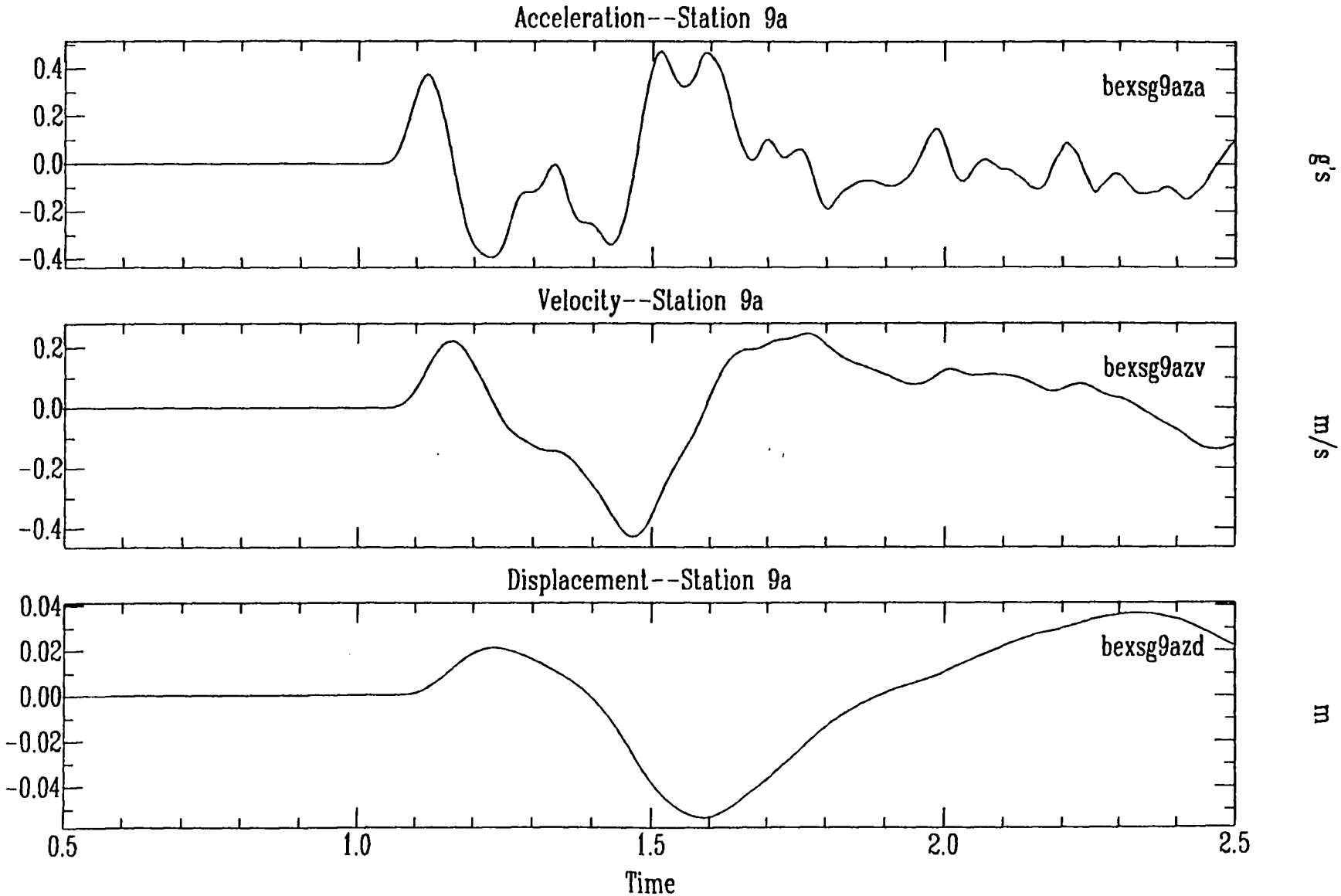

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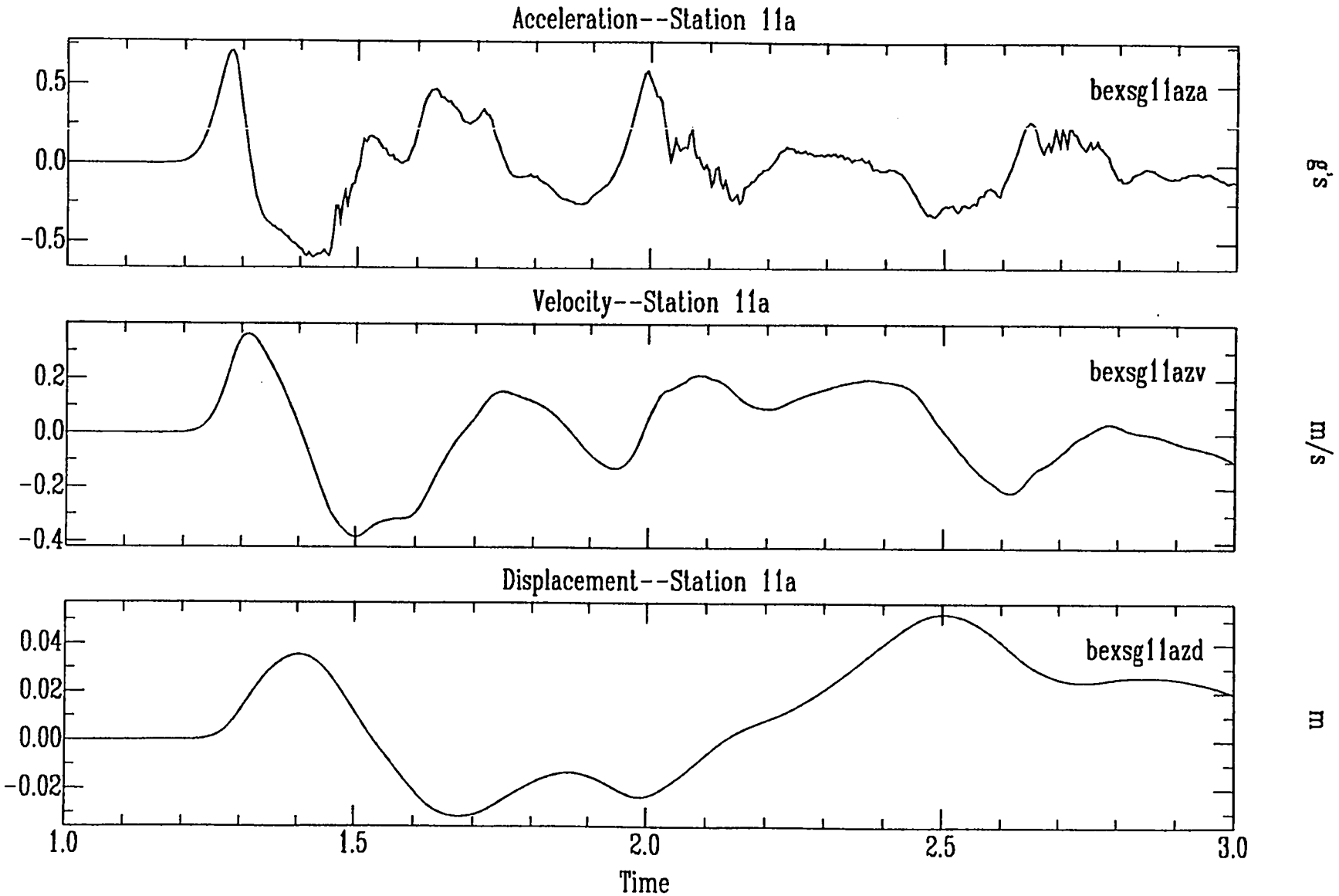

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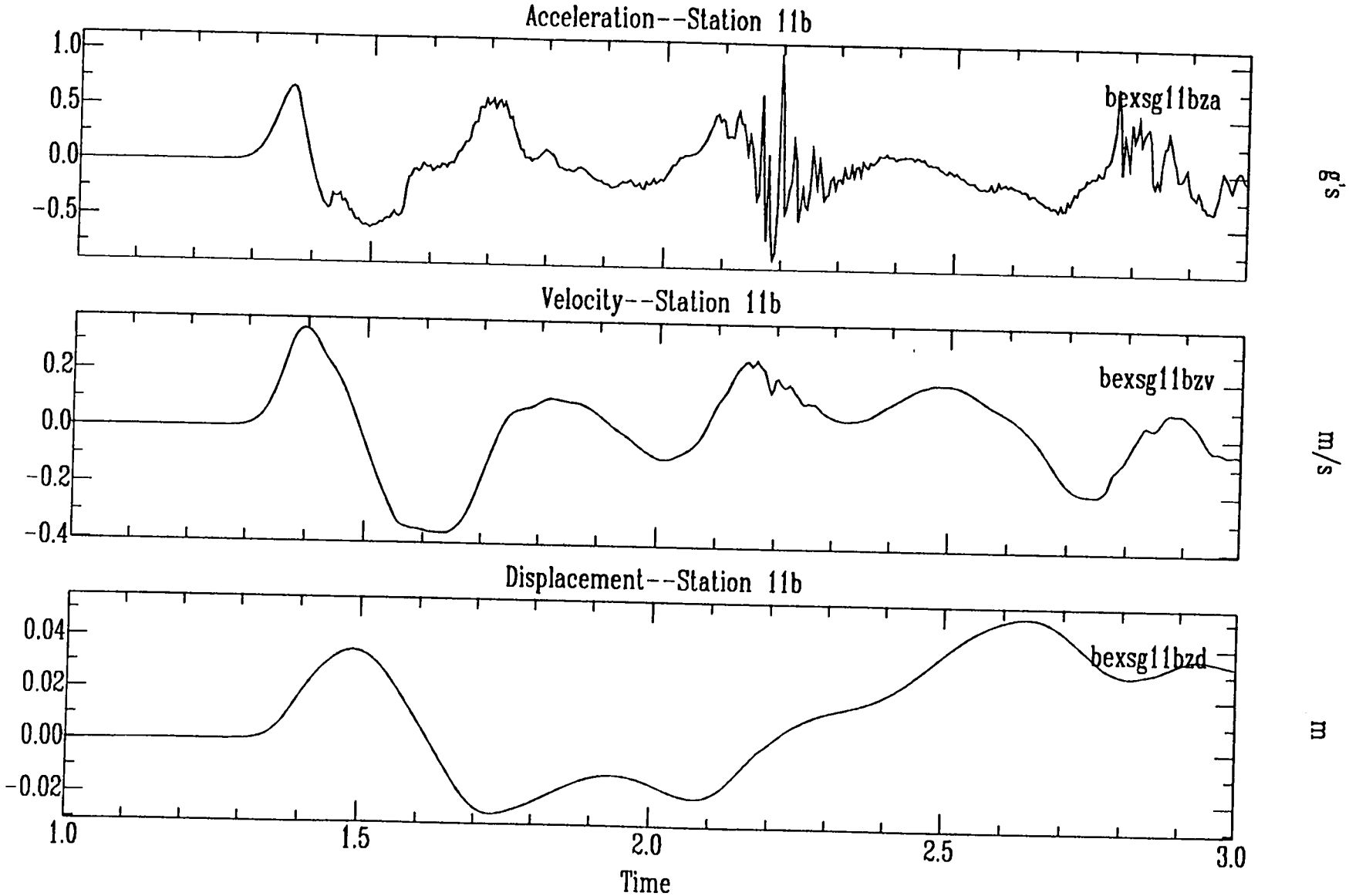

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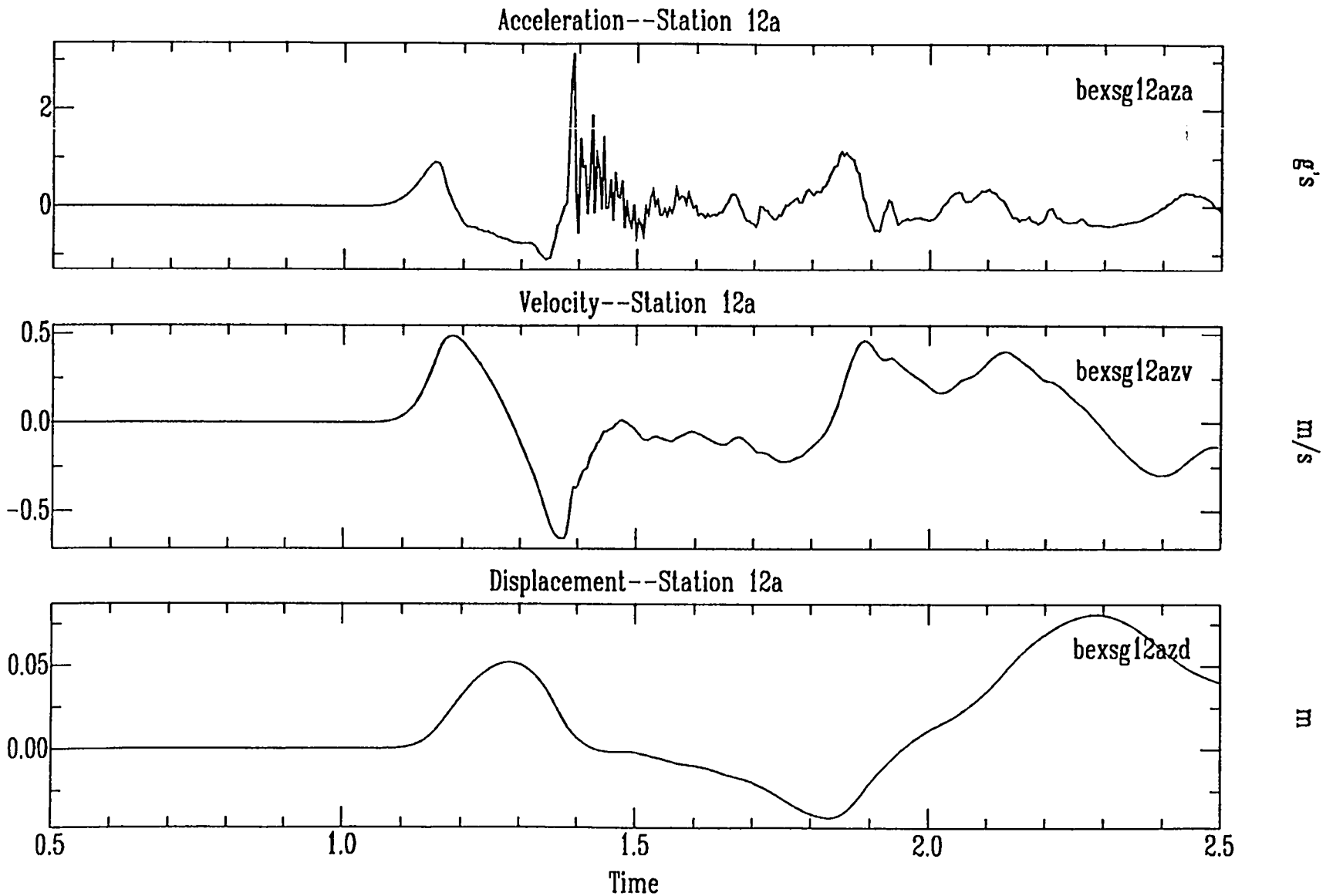

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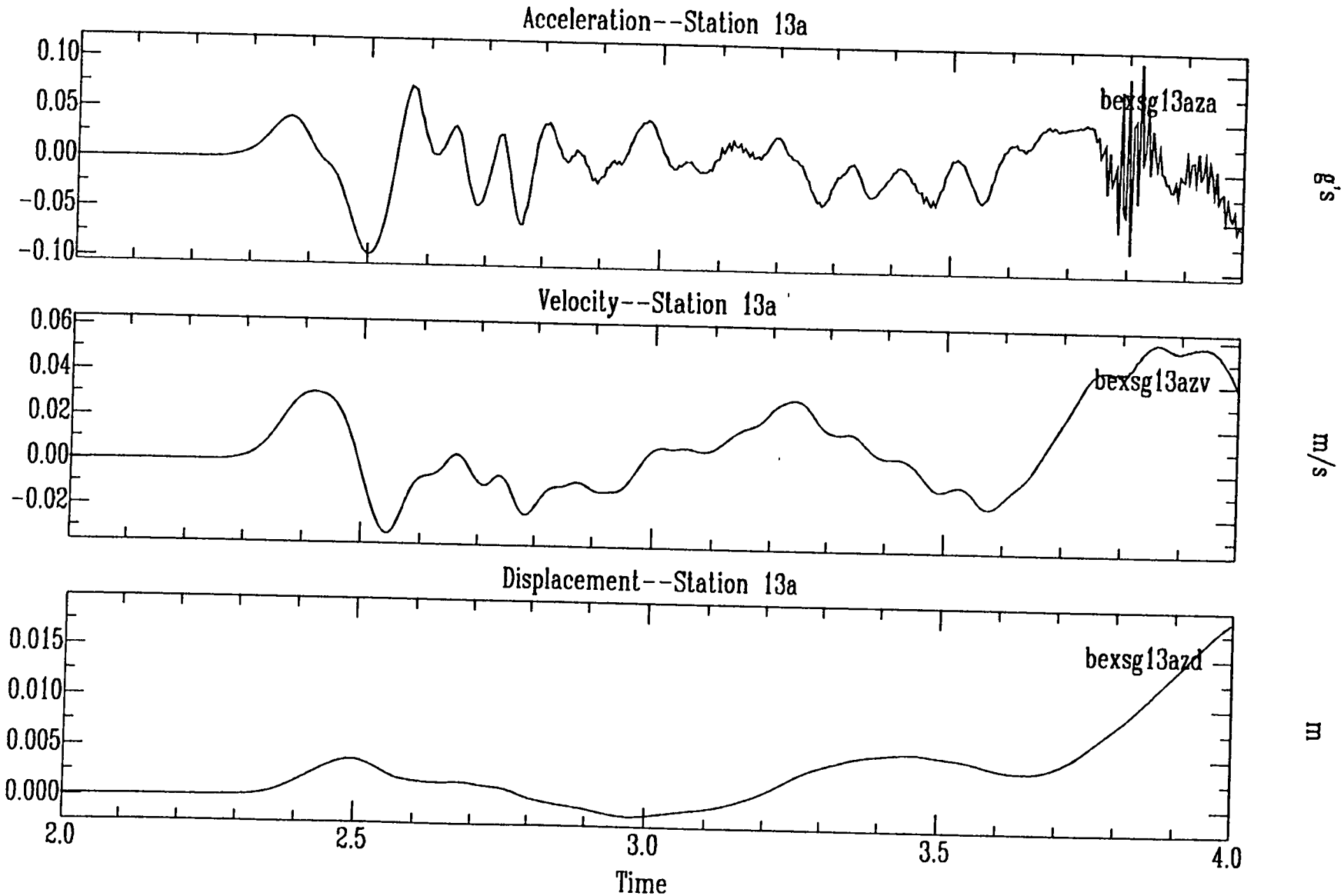

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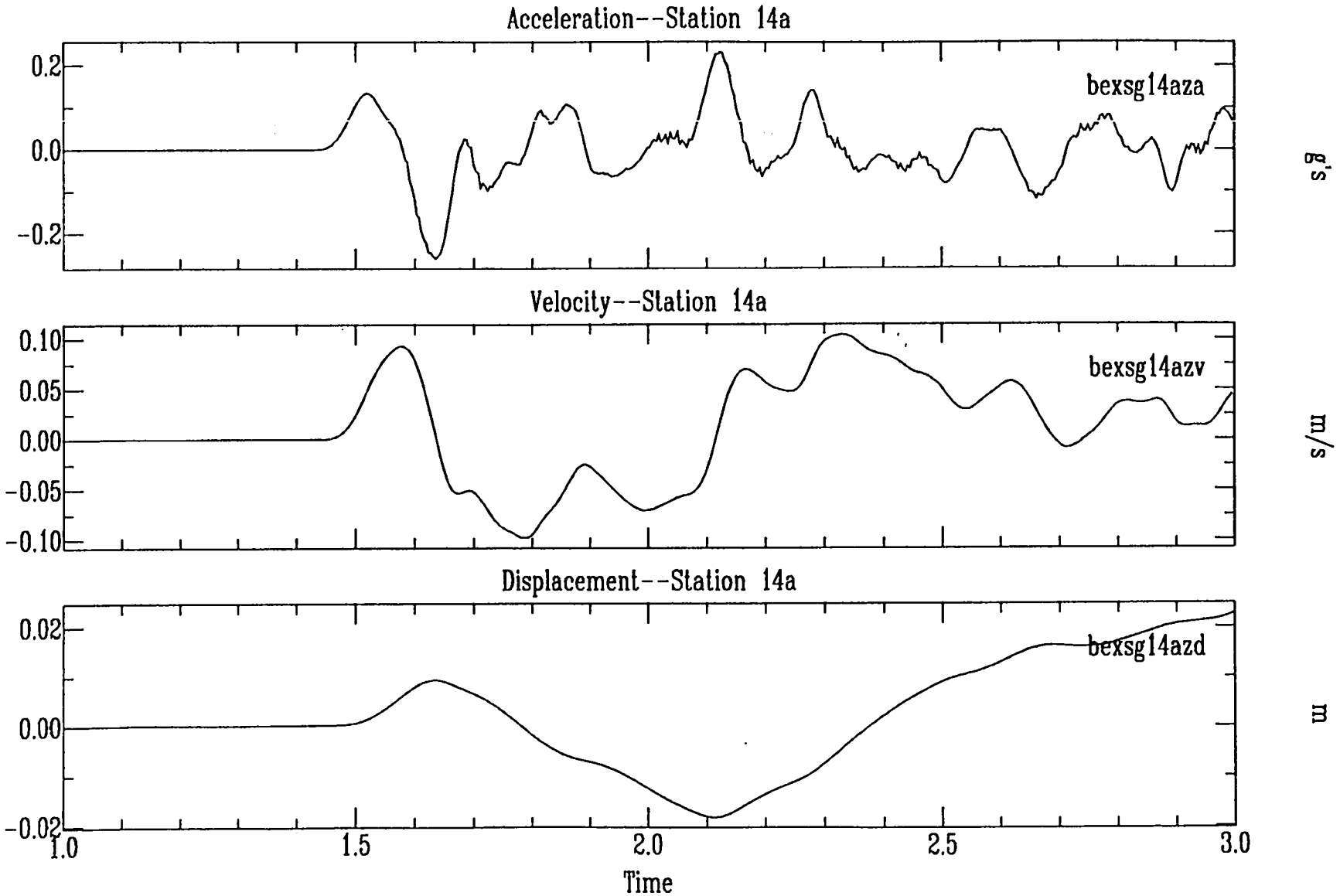

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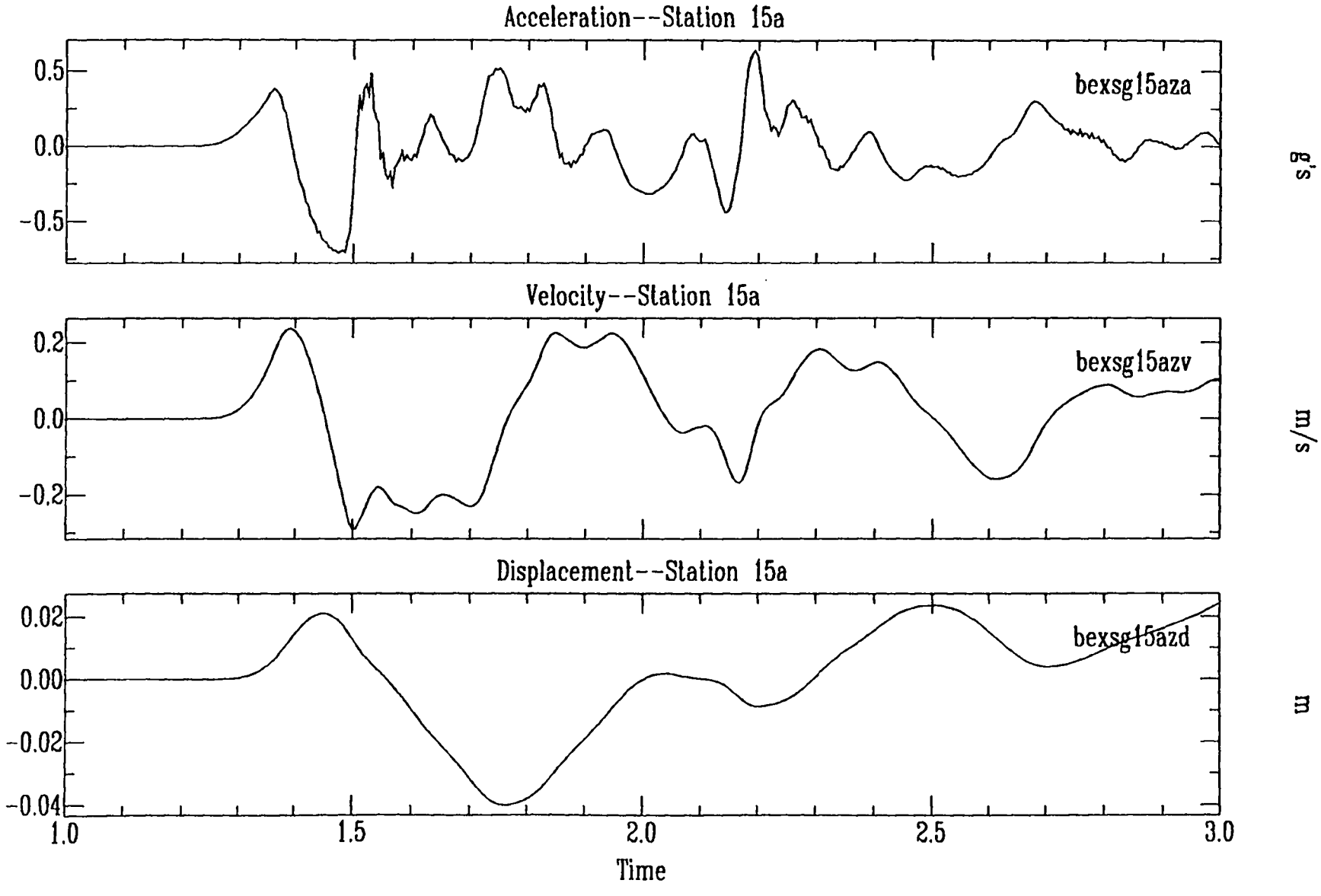

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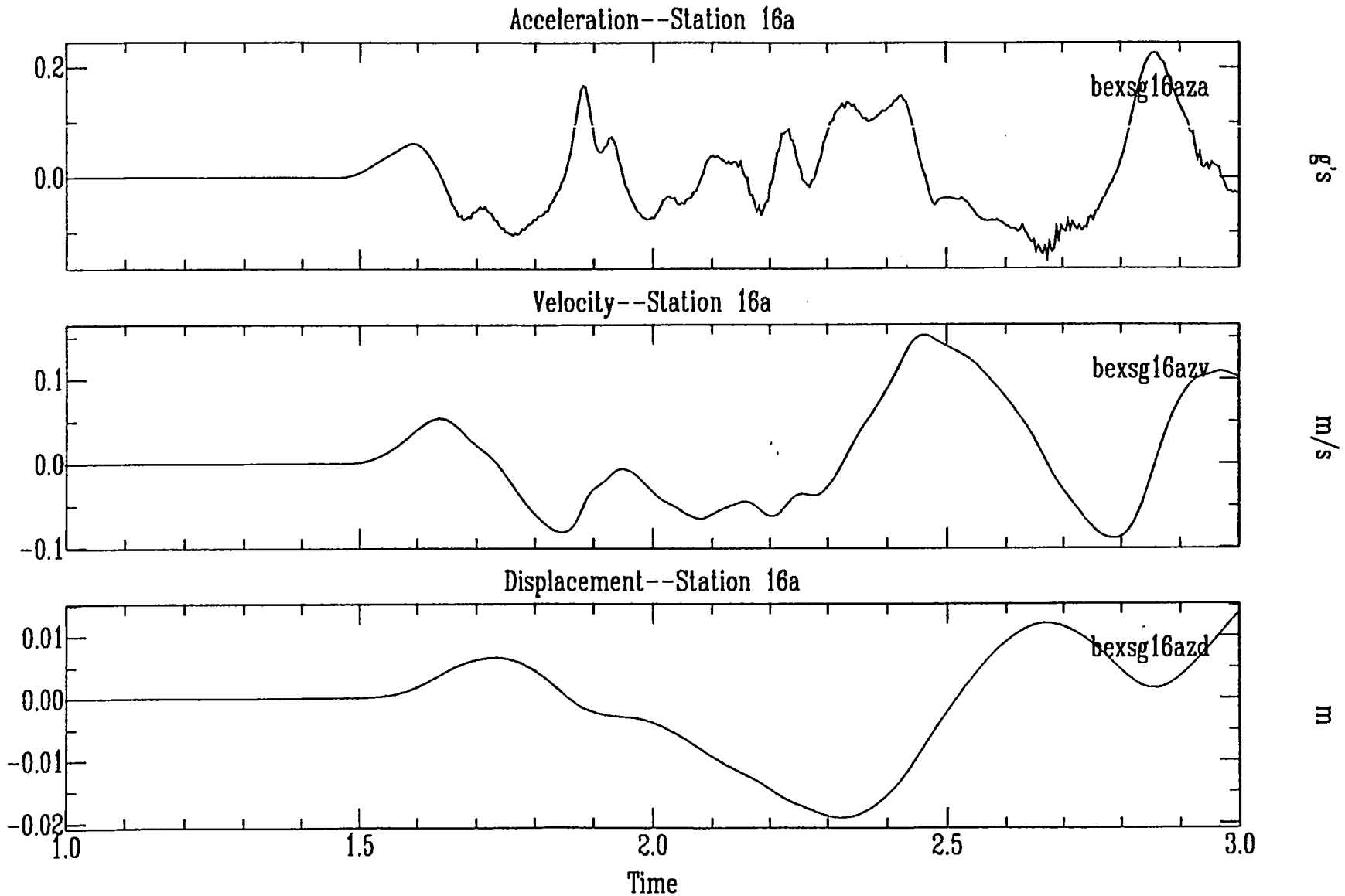

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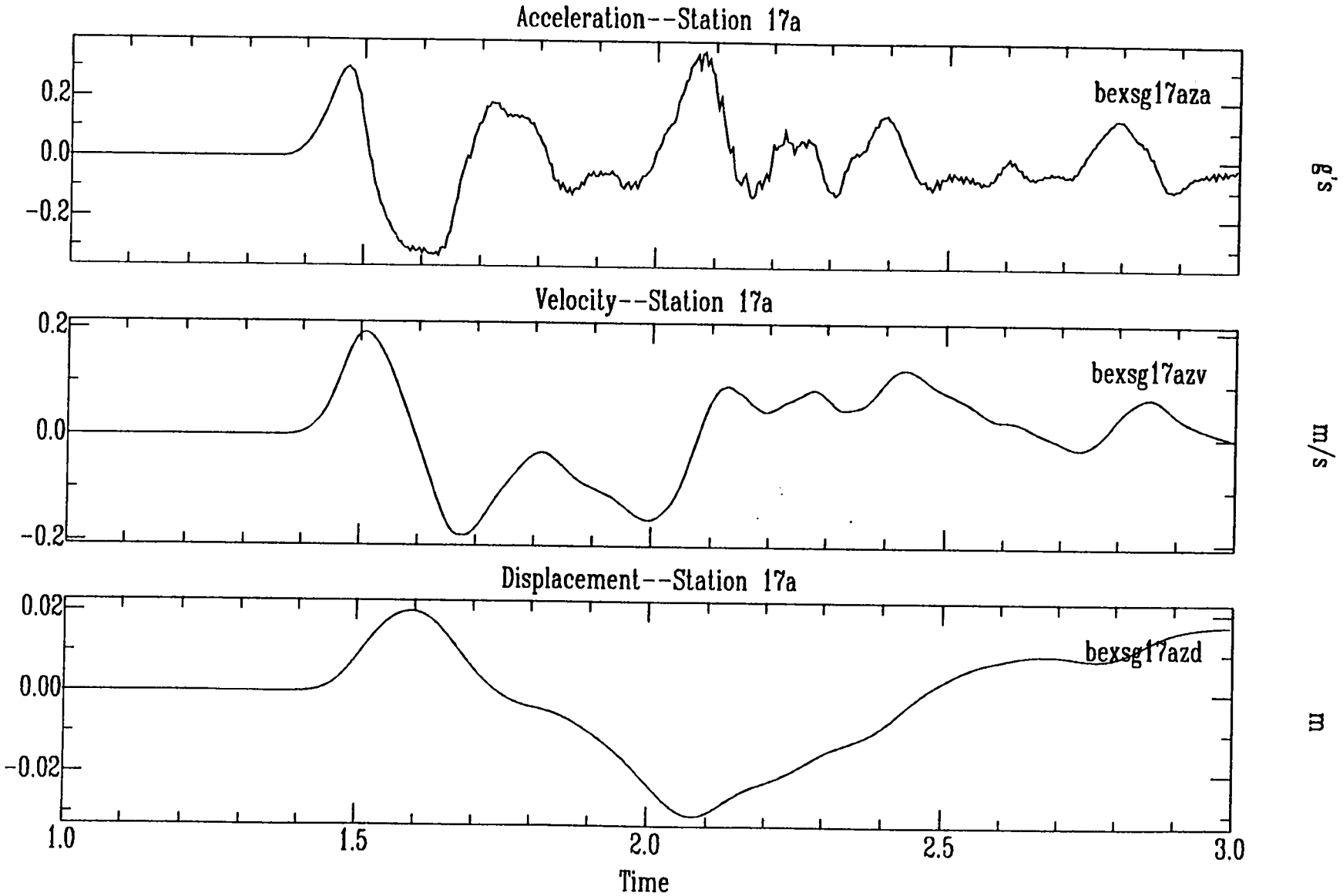

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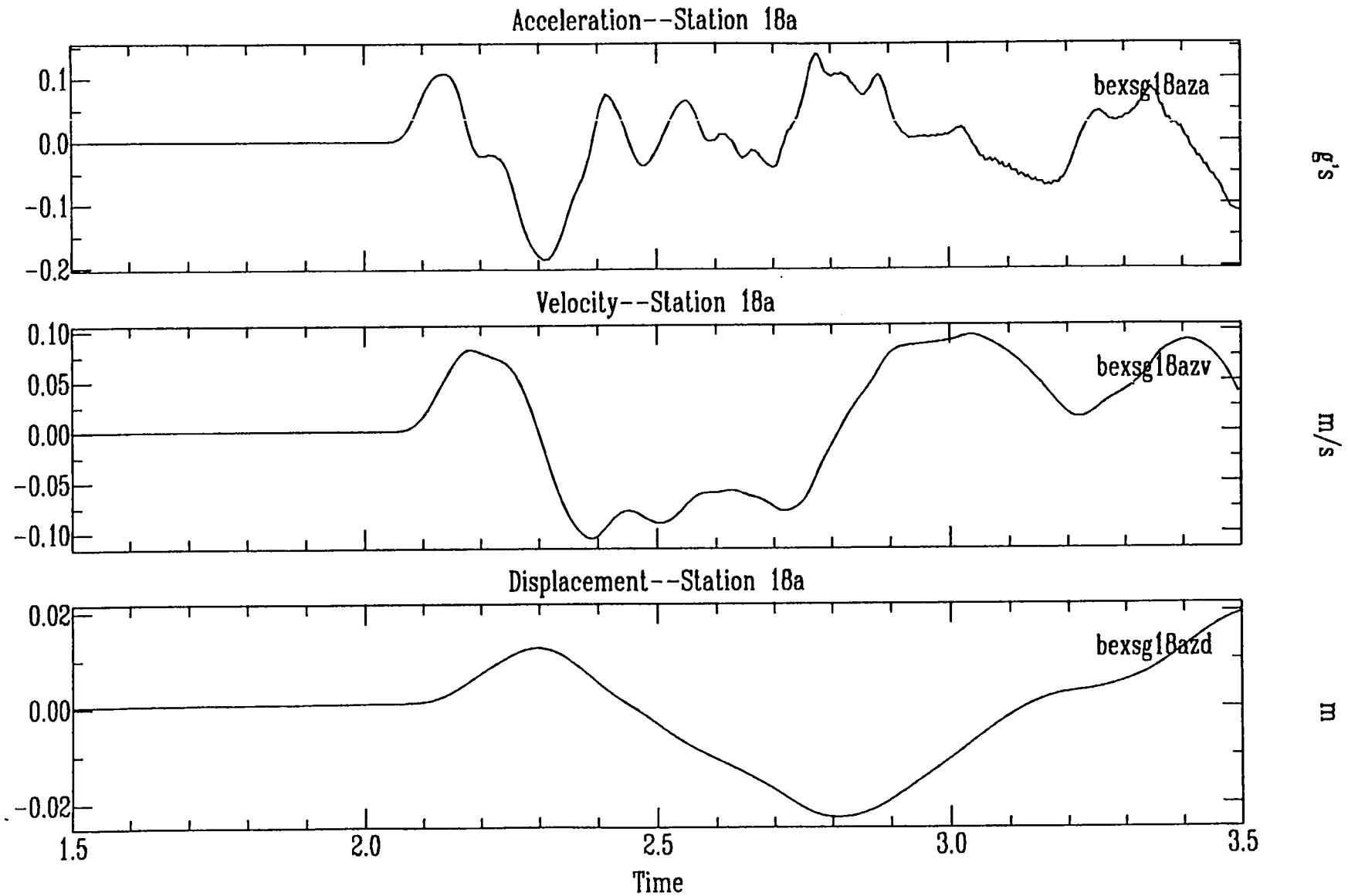

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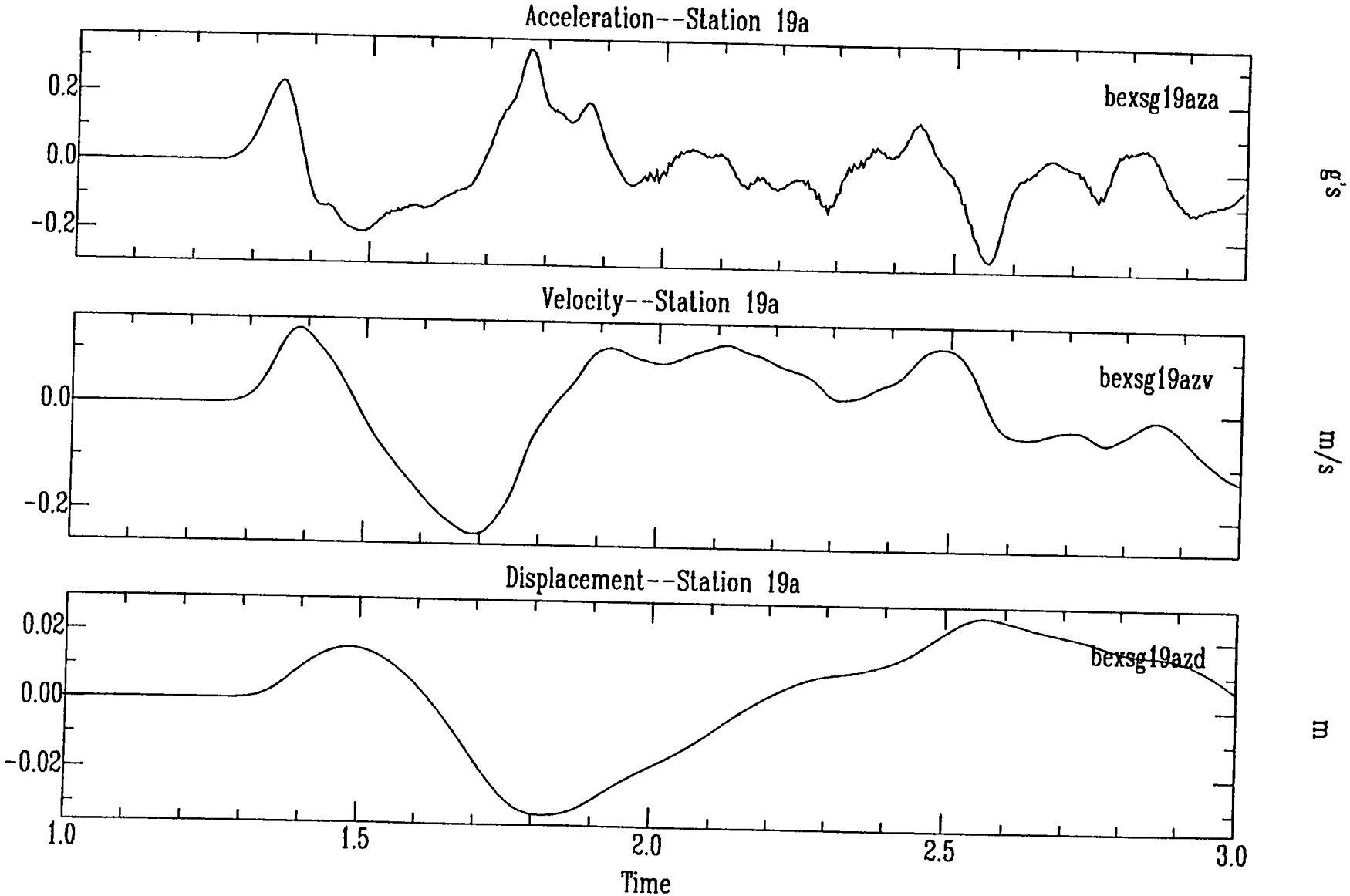

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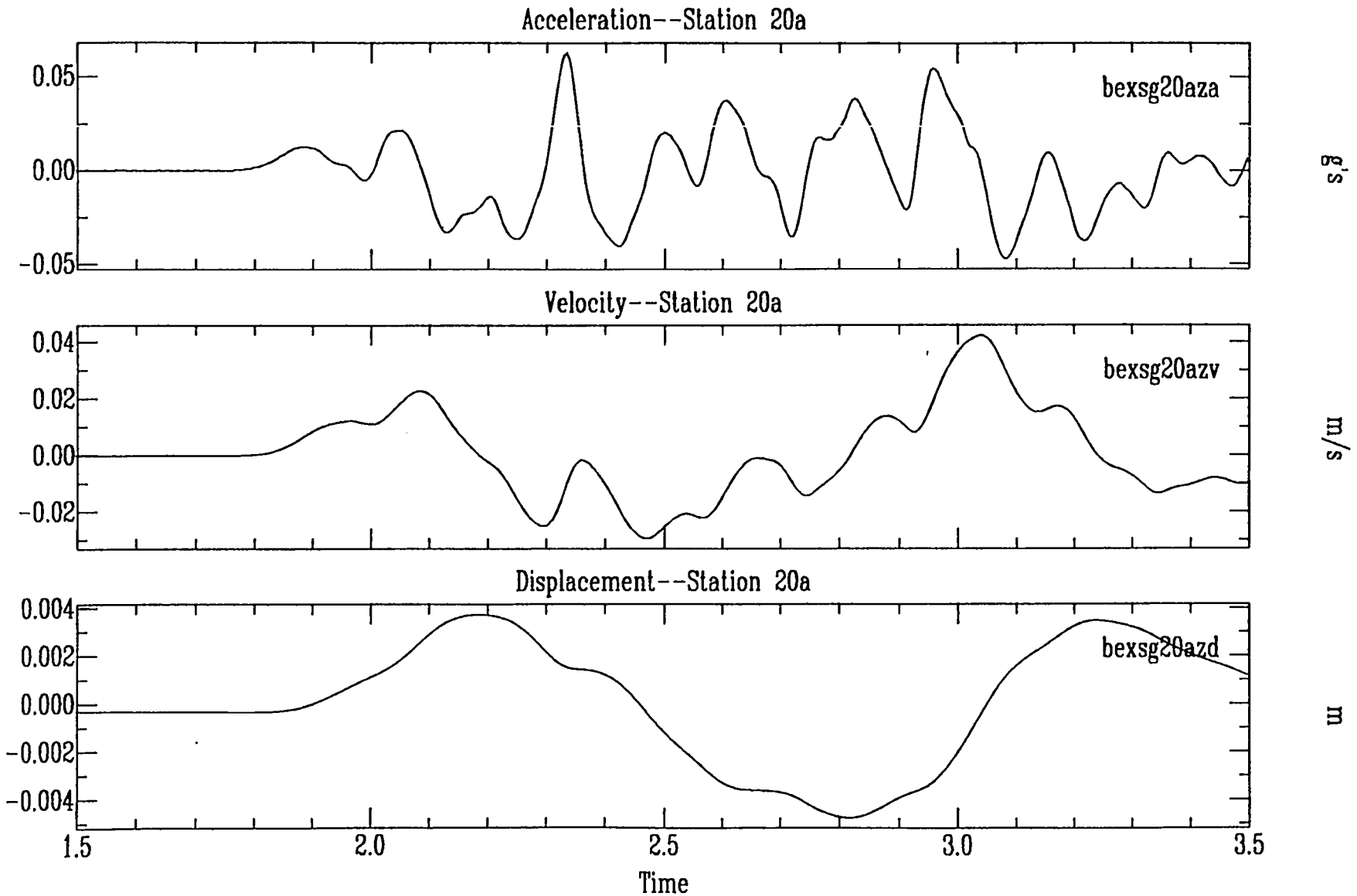

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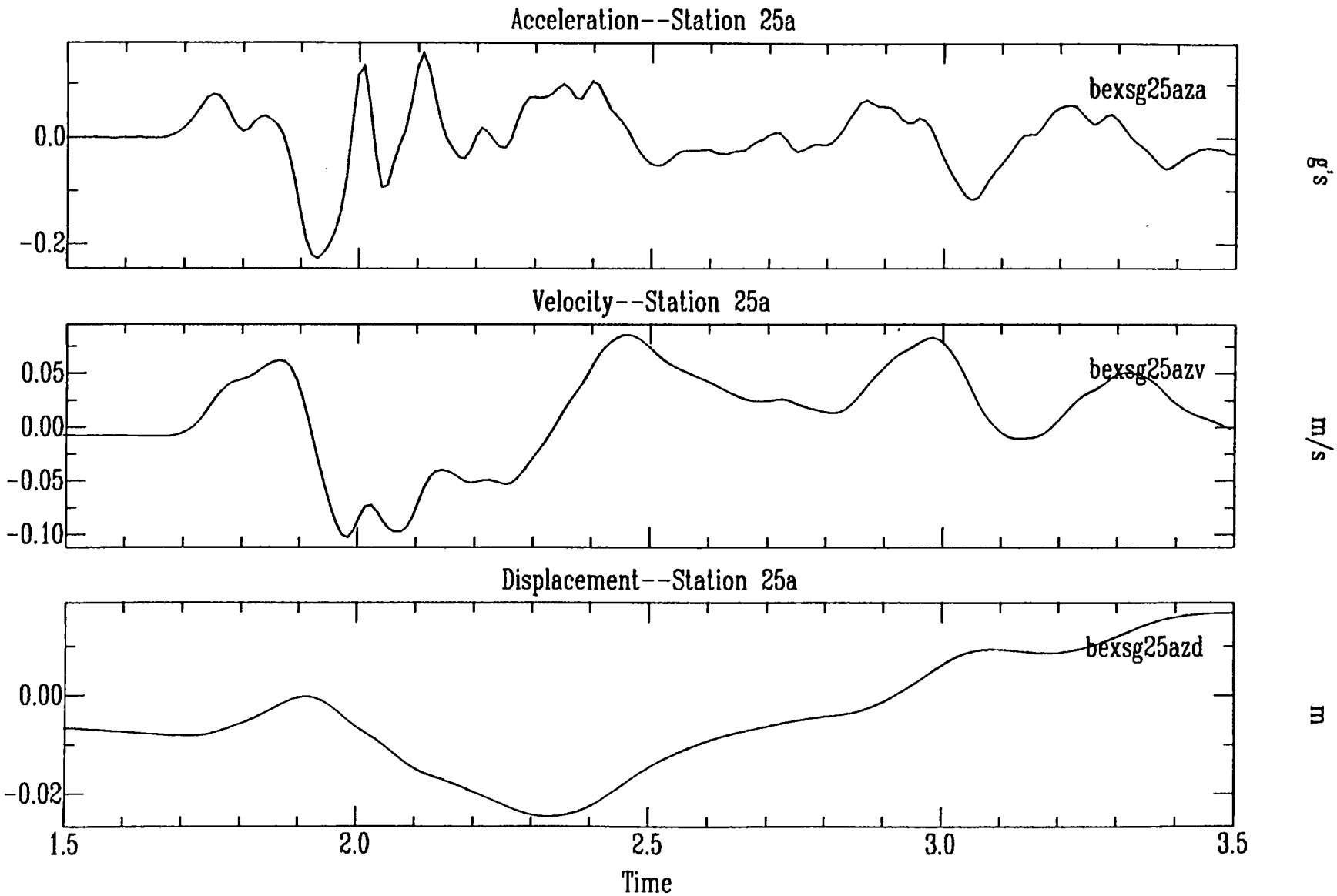

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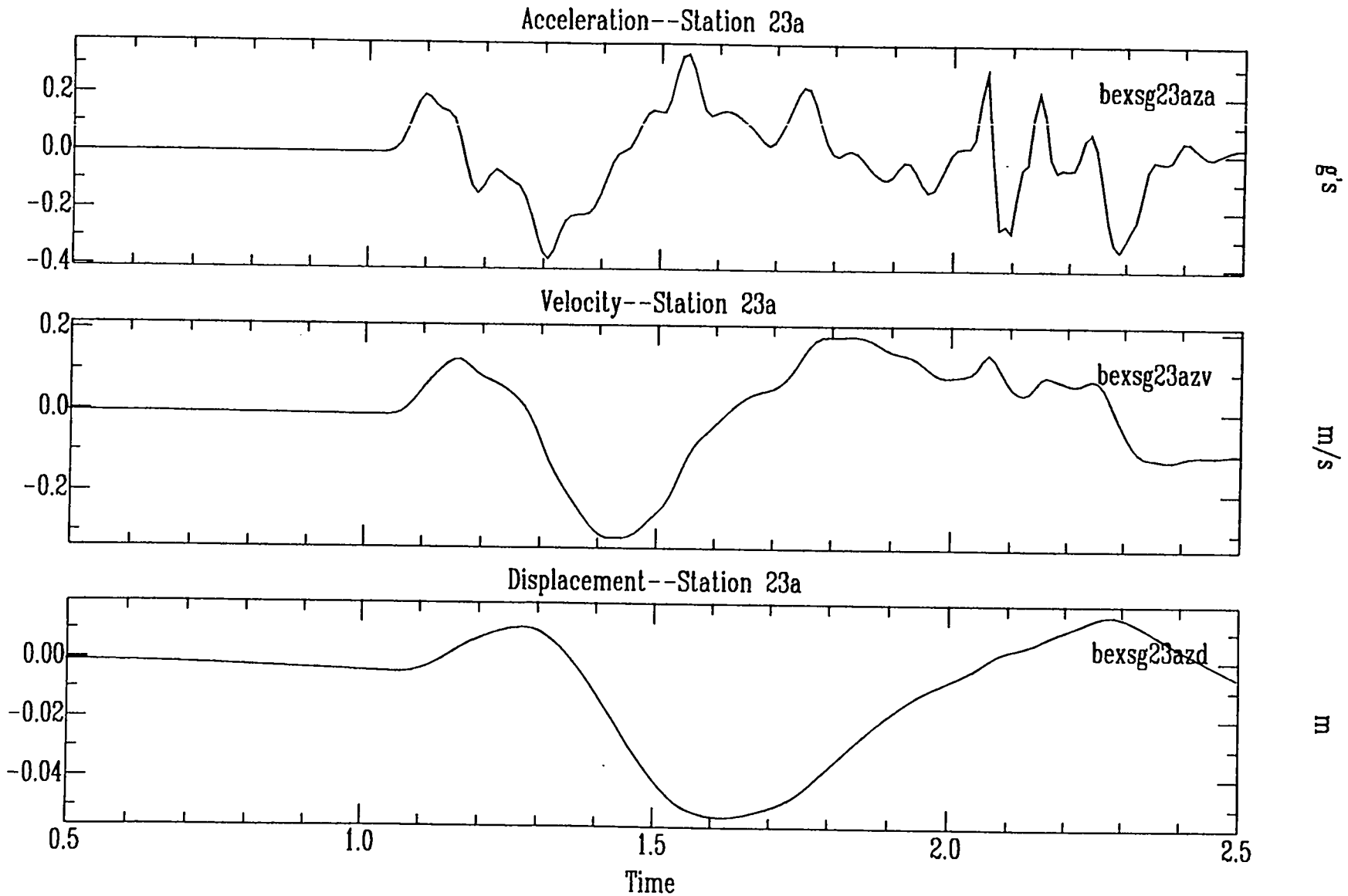

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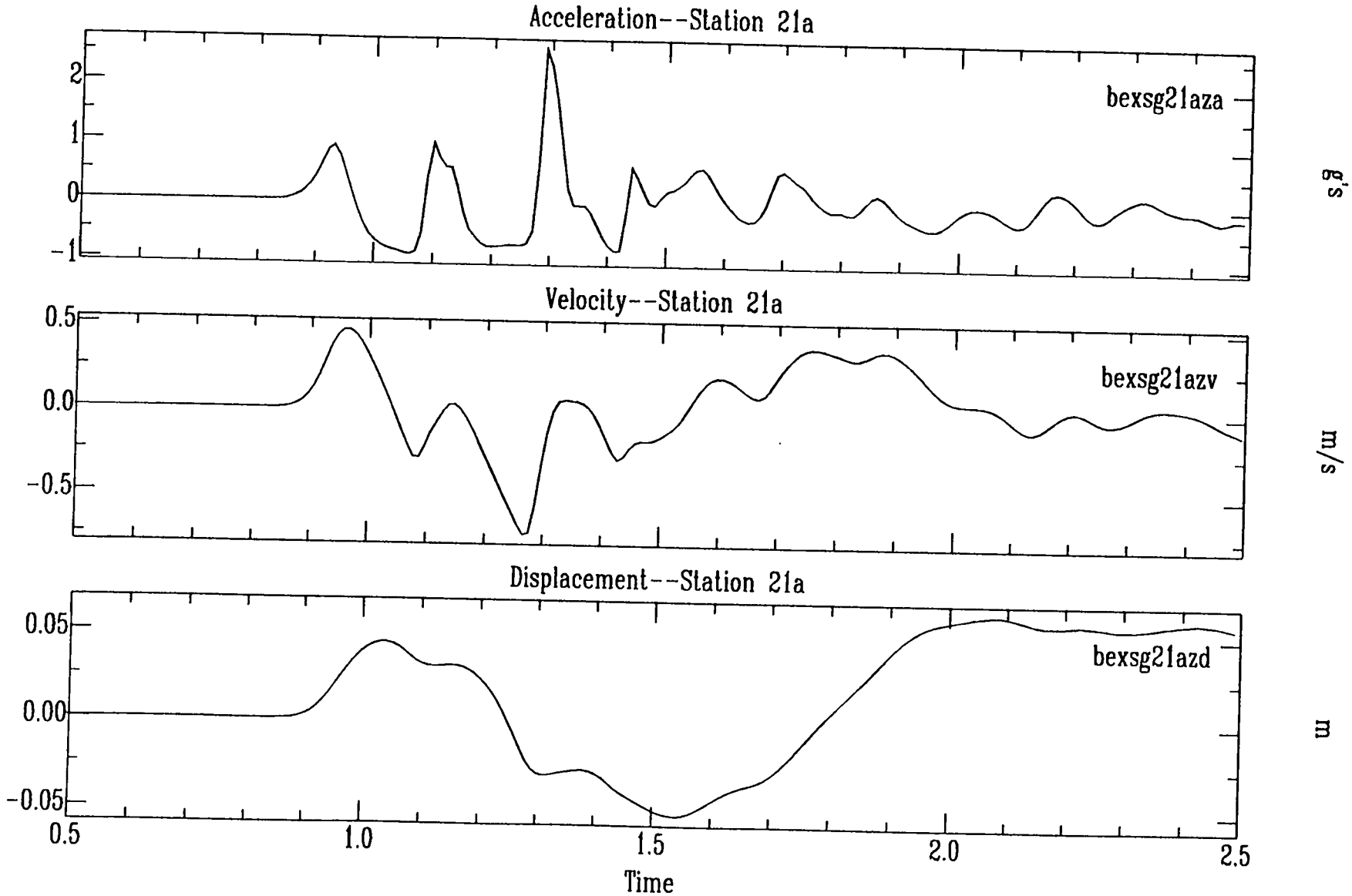
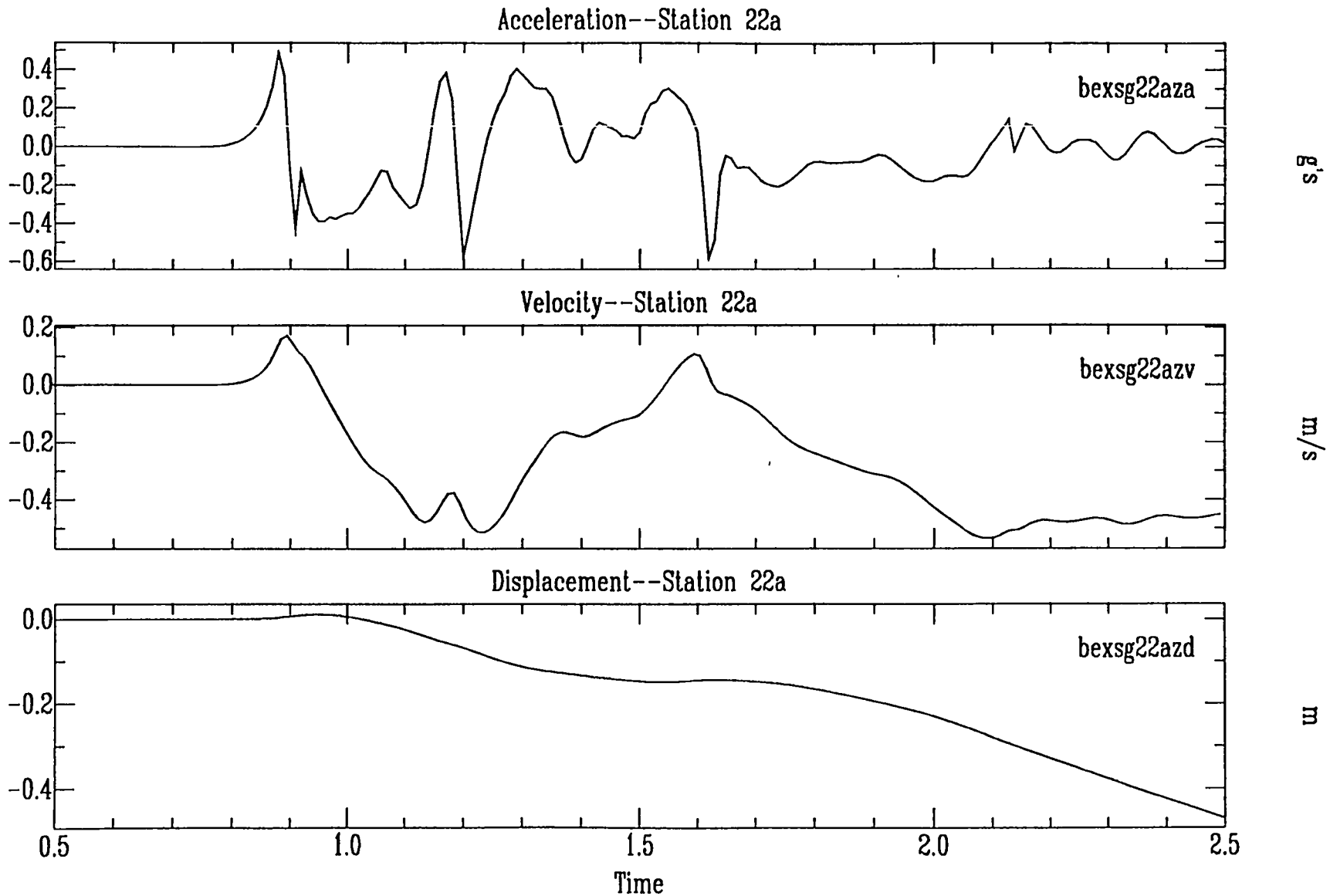


Bexar Surface Ground Motion



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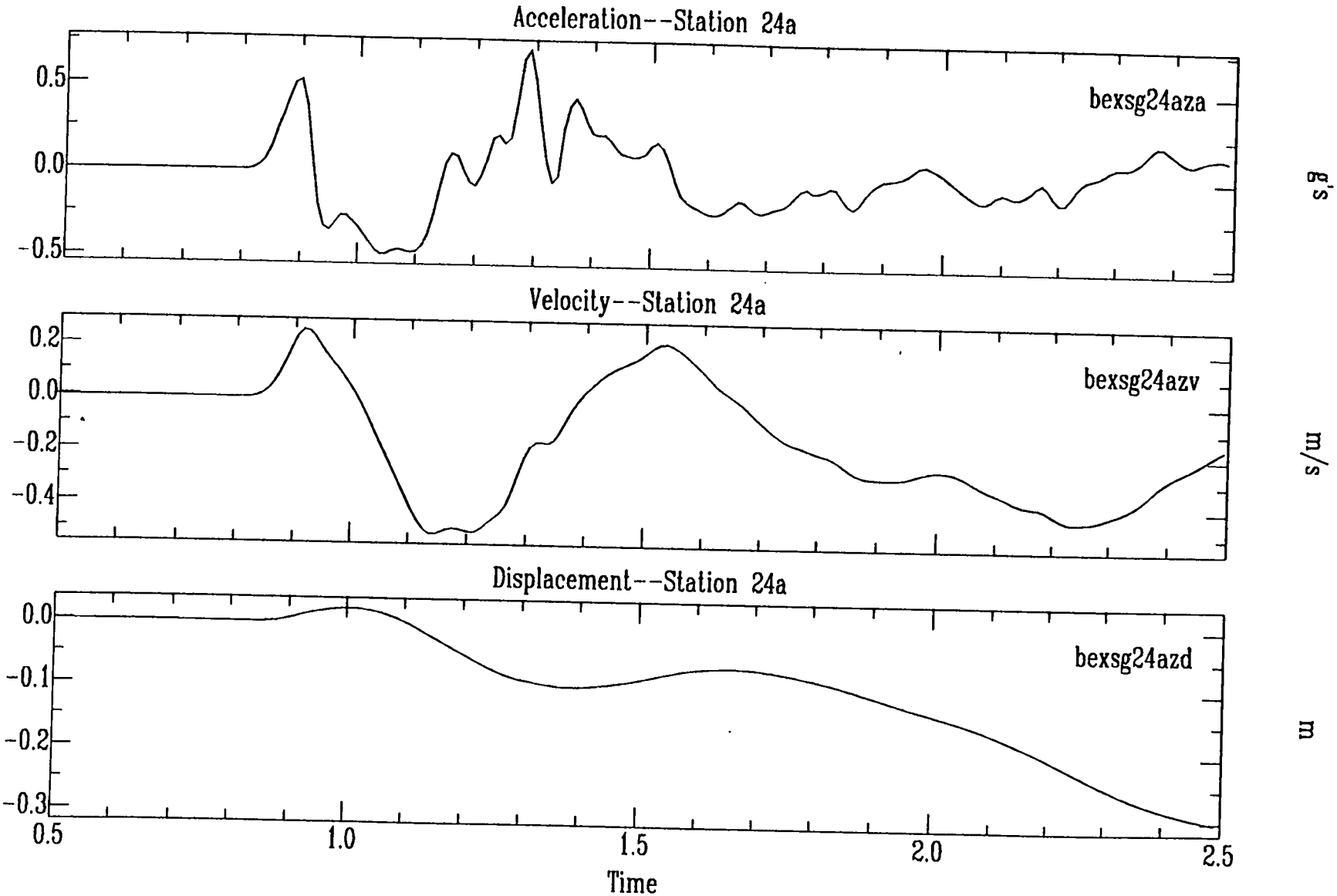

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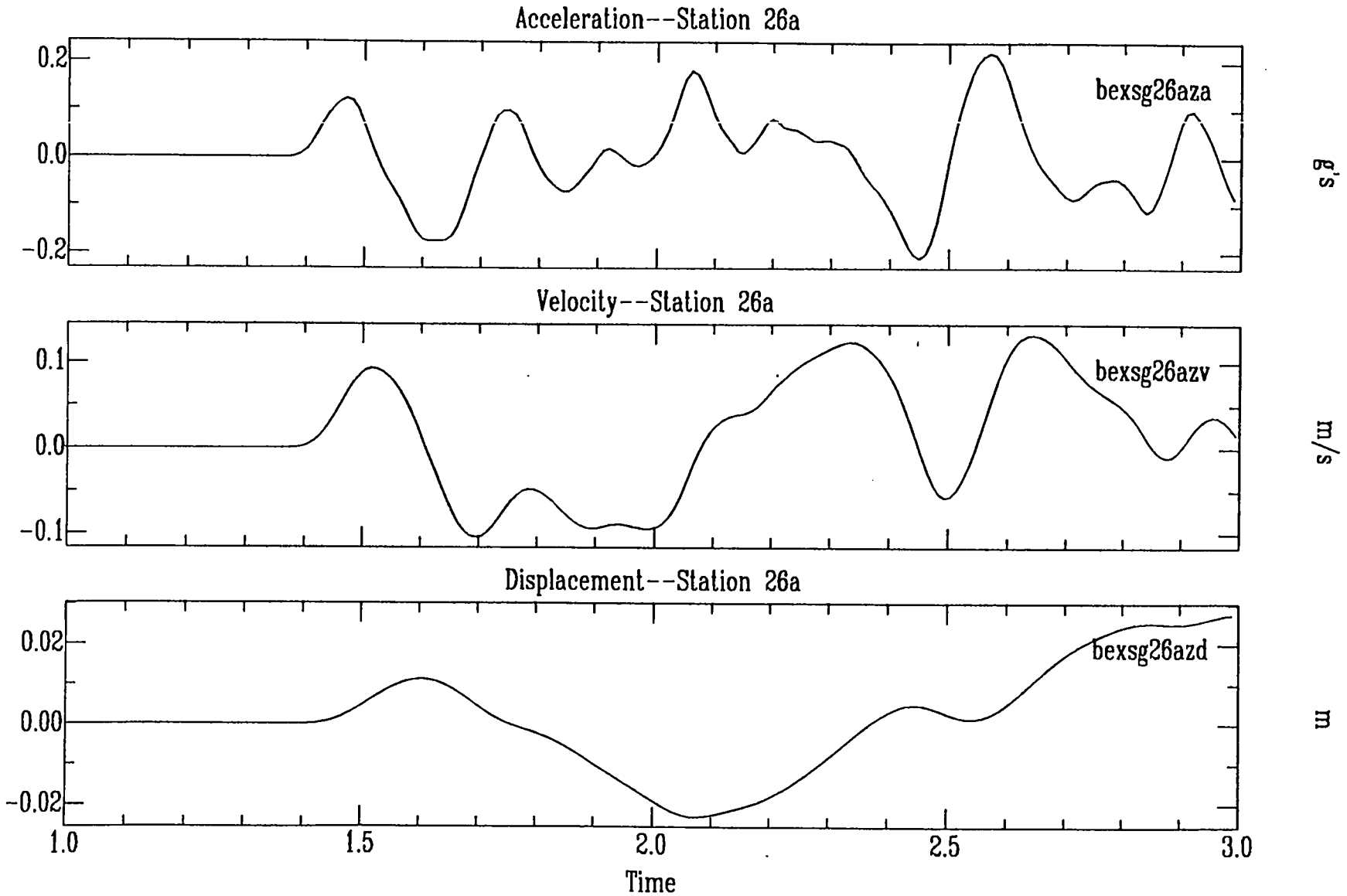

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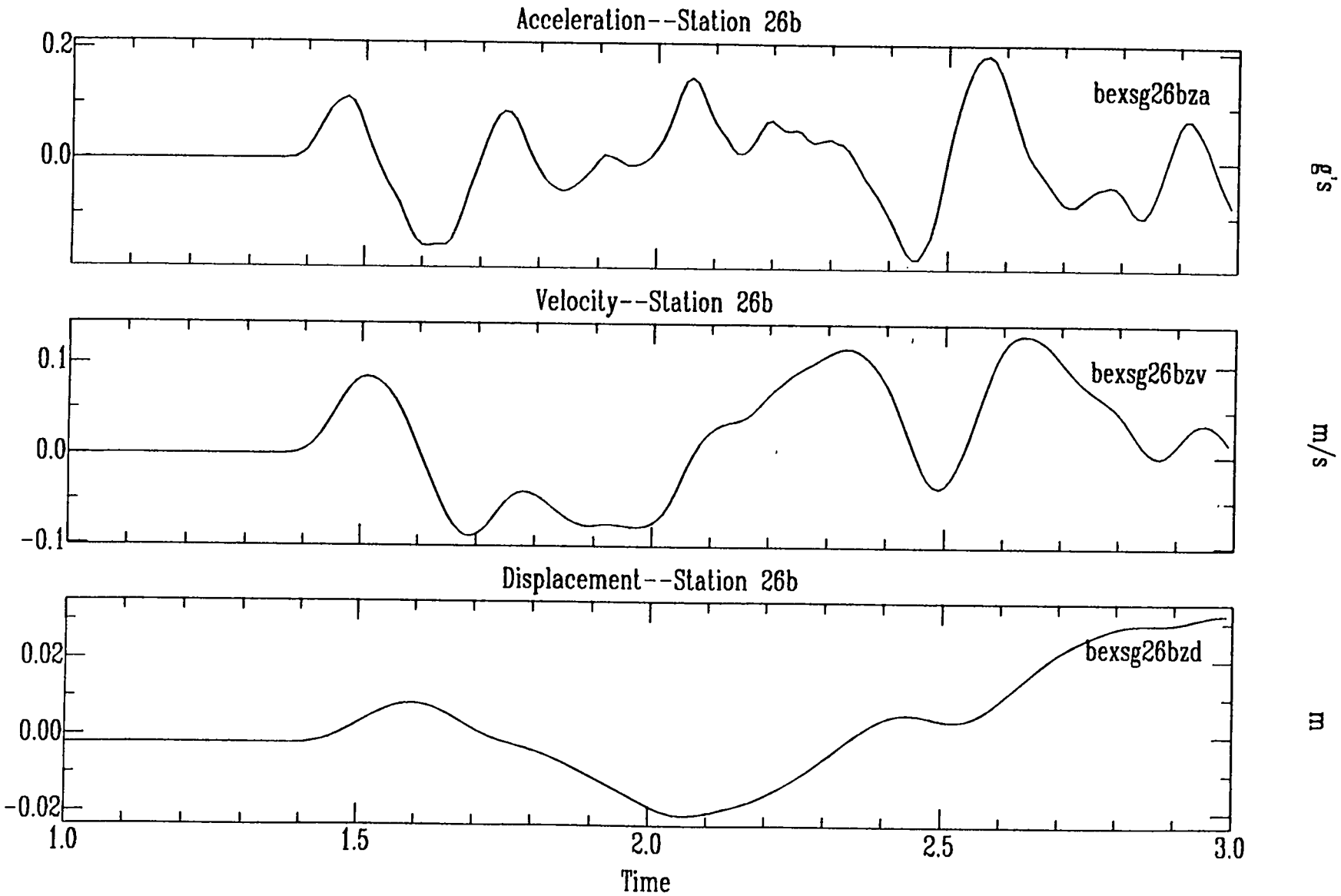

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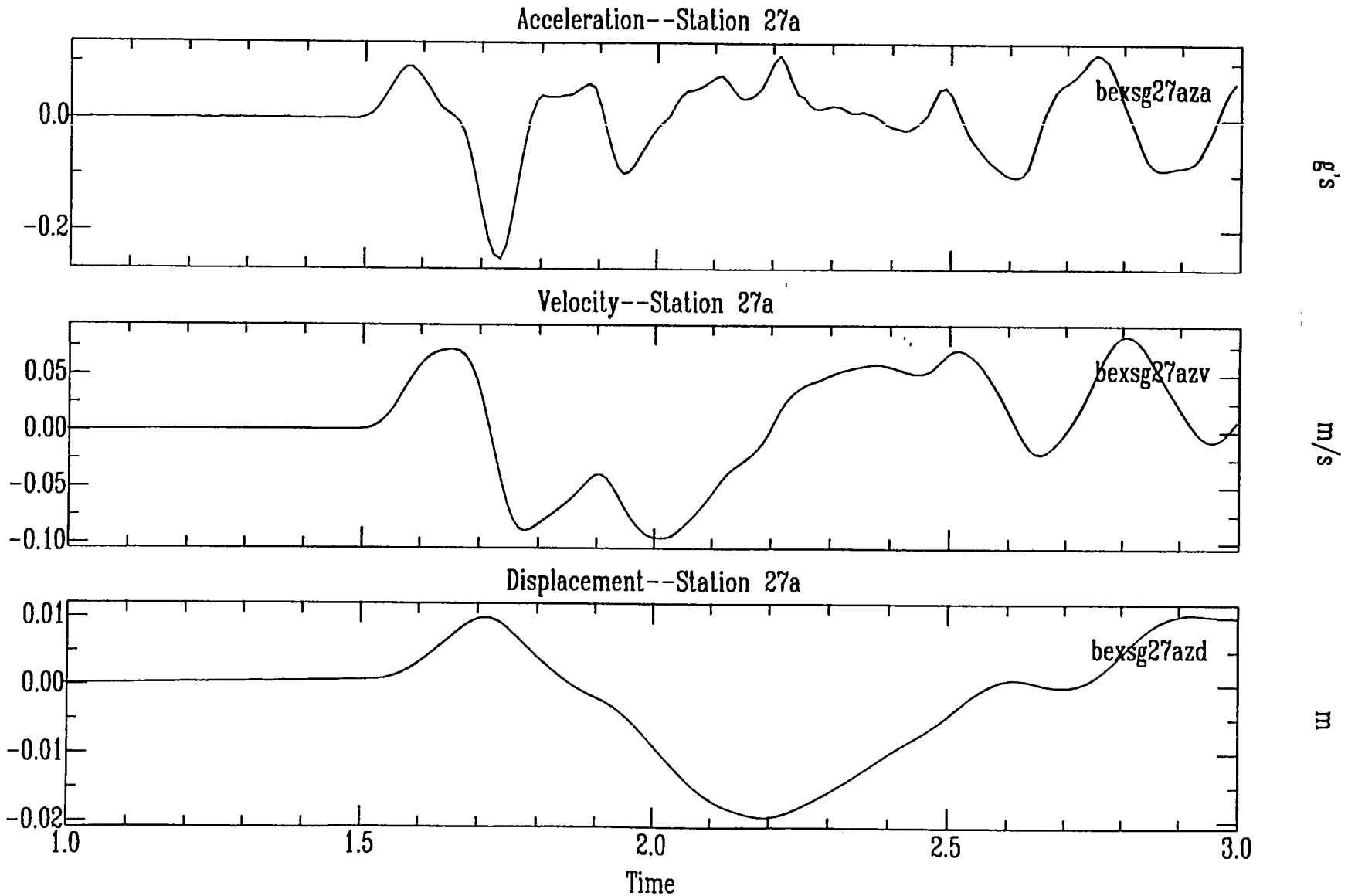

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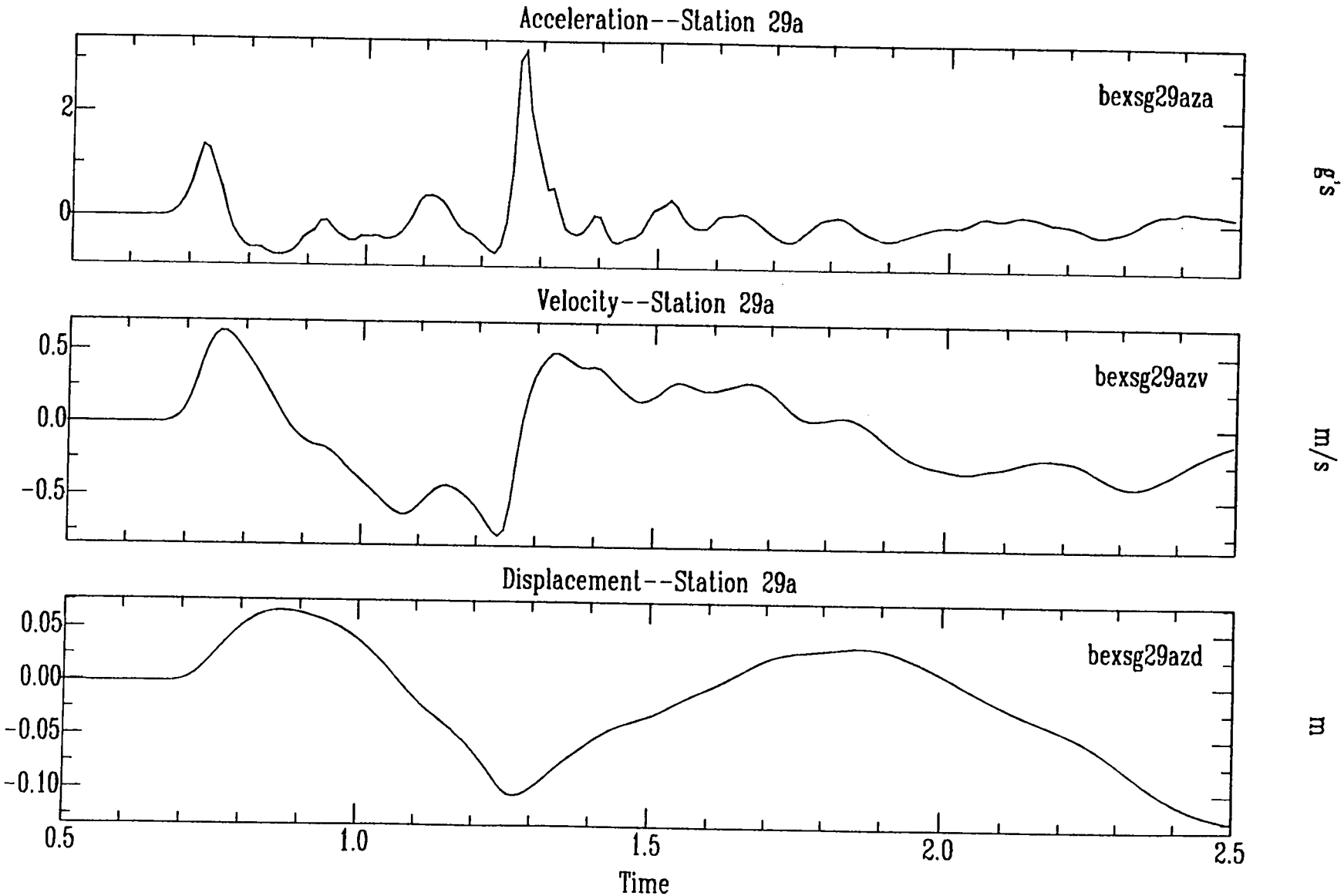

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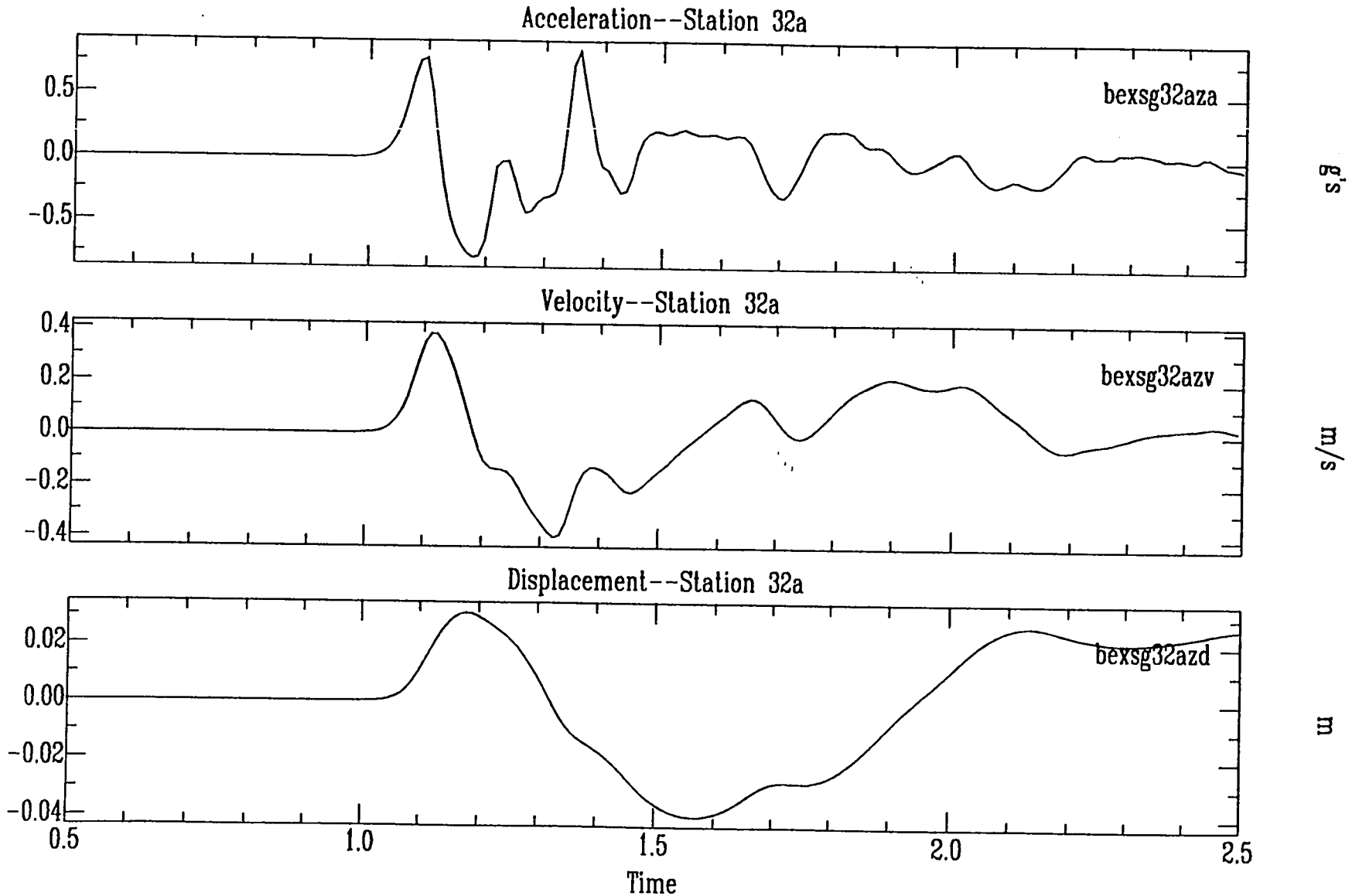

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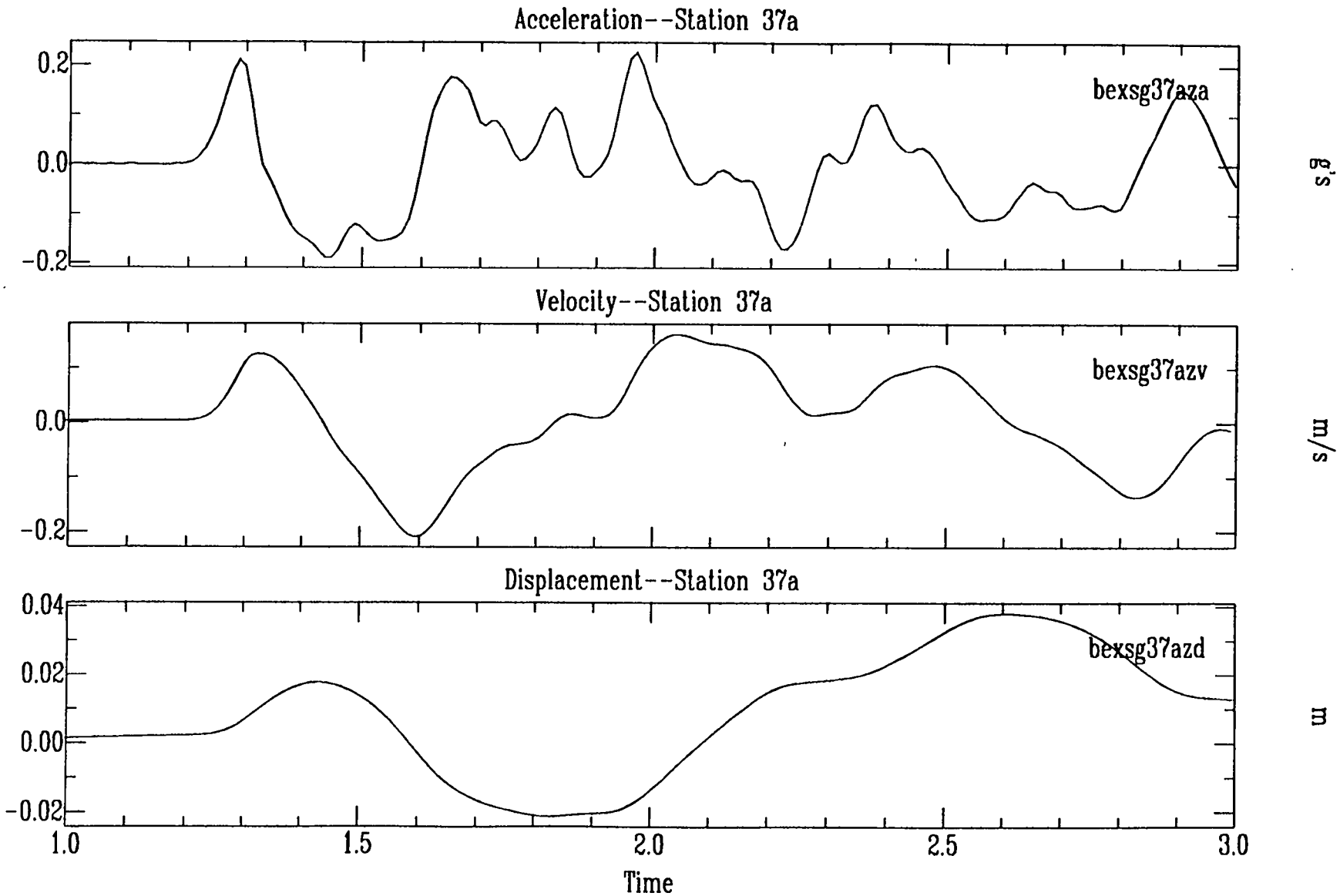


4.10. Junction (U19bg)

Experiment design. For the Los Alamos event Junction, a SIG ground-motion experiment (Table 14 and Fig. 20) and a standard J-8 accelerometer array of 12 stations were deployed (Table 15 and Fig. 19). Junction was fired 26 March 1992. Hole U19bg is located in the central part of Area 19, in close proximity to U19ad (Chancellor), U19ar (Cybar), and 19ay (Amarillo). Figure 19 shows the location of U19bg with the predicted spall radius indicated. The seven SIG arrays planned are also indicated.

Results. Weather conditions were a major factor in the SIG experiment. Rain and snow storms prevented fieldwork for most of the week preceding the event, which, together with poor road conditions, prevented the deployment of two of the planned SIG arrays (arrays #1 and #3). SIGs were deployed at 56 sites at five of the planned arrays. The azimuths and approximate distances of each array are listed in Table 14. The SIG deployment used some of the same locations used for the Contact and Amarillo events (though the array numbers were changed for Junction).

For this experiment, two SIGs were deployed at each location: a golf ball and a steel ball. Each ball was placed directly on the ground. A nail with a piece of flagging was pushed into the ground and the ball placed on top. Spacing between the golf ball and steel ball locations at a site was approximately 2 m on arrays #2 and #7; spacing between the two balls on the other arrays was approximately 10 m. Spacing between sites was 50 paces, or approximately 40-50 m.

The J-8 accelerometer data were originally reported out in April 1992 (Memo J-8-92-100, R. S. Fitzhugh to F. N. App). All of the J-8 stations recorded spall signals, which are shown in Fig. 21 (12 pages).

Table 14. Junction SIG Arrays

Array	Distance from SGZ	Azimuth from SGZ
1	2500 m	50
2	2000 m	100
3	750 m	170
4	1500 m	335
5	2500 m	320
6	2250 m	290
7	2000 m	240

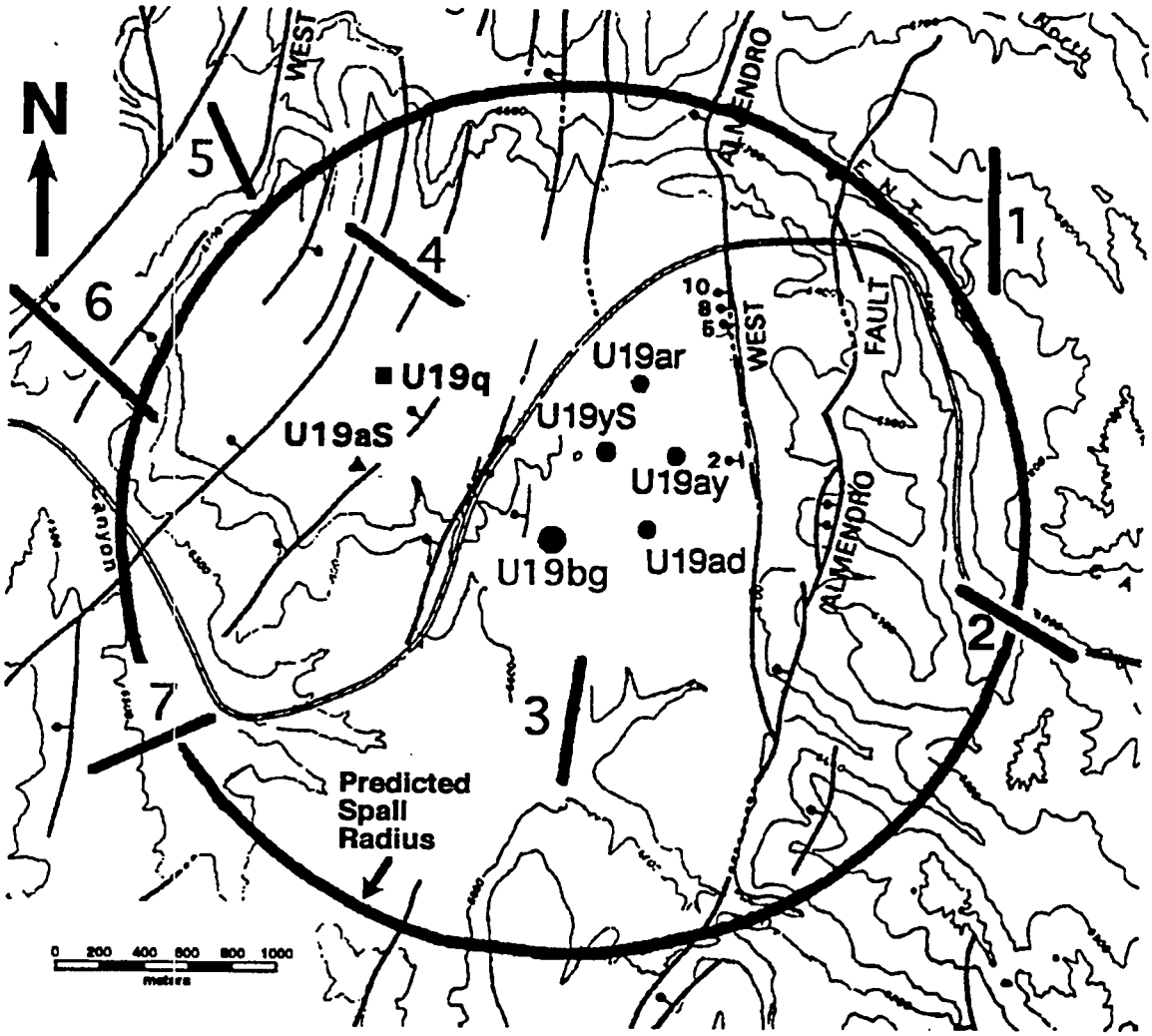


Fig. 19. Junction SIG experiment plan.

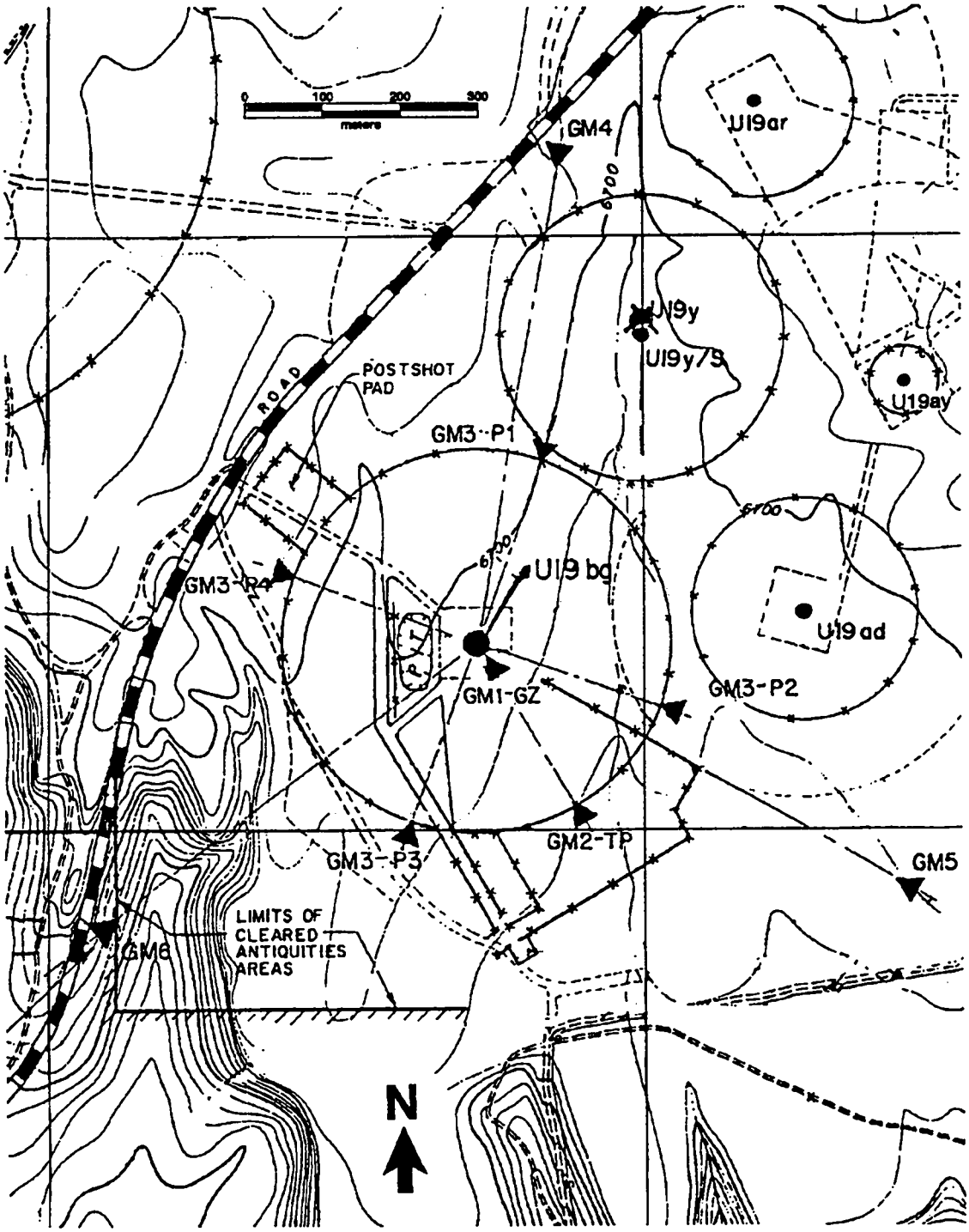


Fig. 20. Junction station map.

Table 15. Junction Ground-Motion Station Data

Station Name	Station Loc u19bg	Accelerometer	Northing (m) 279898	Easting (m) 179617	Slant Range 622 (m) DOB	Travel Time
JUNGM1A	15m S30E	Endevco 10 g	279884	179625	622	0.297
JUNGM1B	15m S30E	Endevco 25 g	279884	179625	622	0.3
JUNGM1C	15m S30E	Endevco 25 g	279884	179625	622	0.298
JUNGM2A	250m S20E	Endevco 25 g	279663	179702	670	0.313
JUNGM2B	250m S20E	Endevco 25 g	279663	179702	670	0.313
JUNGM3P1	250m N20E	Endevco 25 g	280132	179702	670	0.303
JUNGM3P2	250m S70E	Endevco 25 g	279812	179852	670	0.306
JUNGM3P3	250m S20W	Endevco 25 g	279663	179531	670	0.307
JUNGM3P4	250m N70W	Endevco 25 g	279983	179382	670	0.327
JUNGM4A	622m N10E	Endevco 20 g	280509	179725	879	0.39
JUNGM5A	622m S60E	Endevco 20 g	279586	180155	880	0.42
JUNGM6A	622m S53W	Endevco 20 g	279526	179118	880	0.375

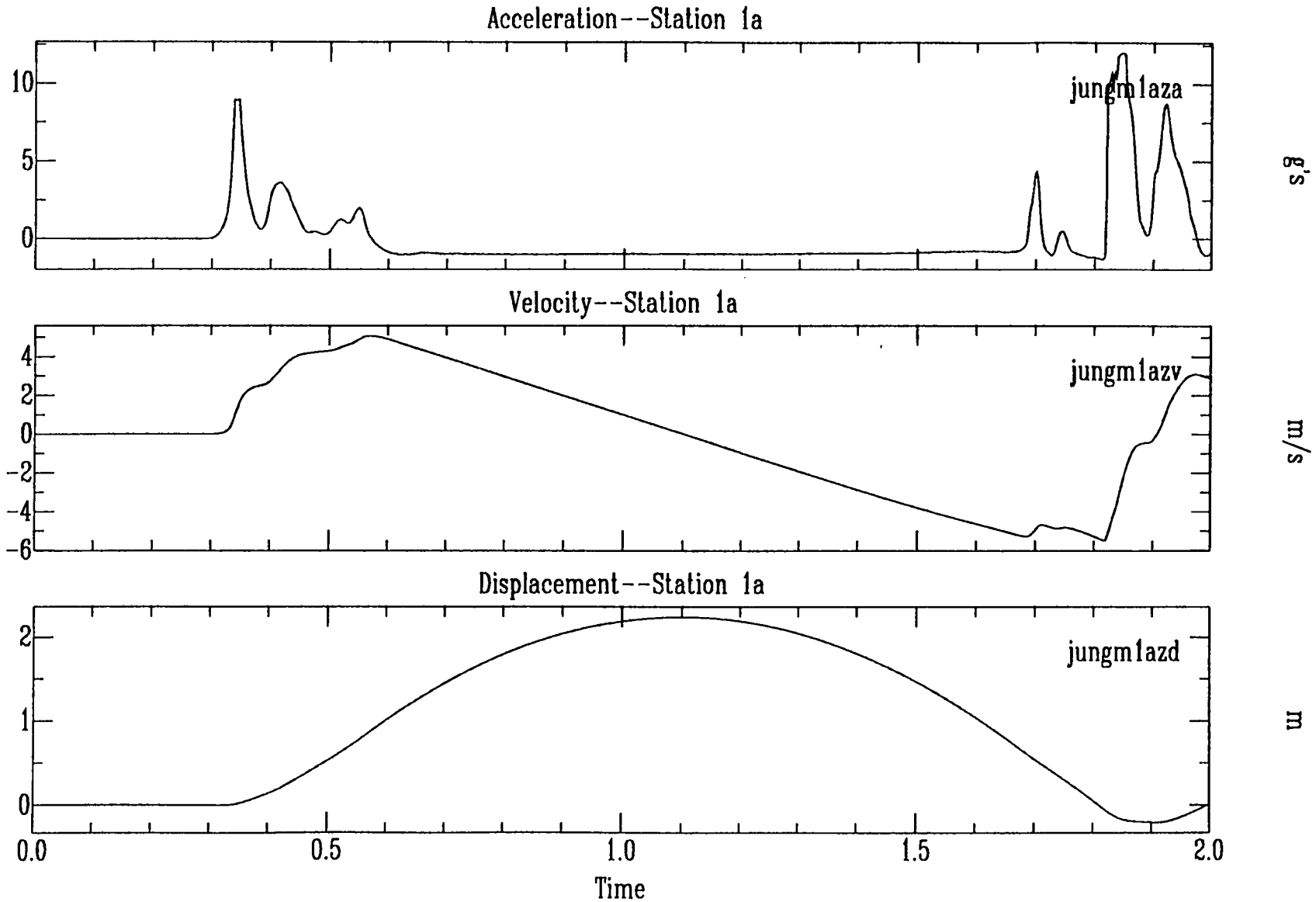
Table 16. Junction SIG Results

Location	Golf Ball Dist (cm)	Golf Ball Azi	Steel Ball Dist (cm)	Steel Ball Azi	Comment
2-1	8.9	125	3.8	60	
2-2	11.4	85	0.0	0	
2-3	0.0	0	0.0	0	
2-4	****	***	3.8	340	
2-5	****	***	21.6	135	
2-6	0.0	0	0.0	0	
2-7	11.4	225	2.5	125	
2-8	5.1	305	7.6	285	
2-9	7.6	105	5.1	335	
2-10	35.6	265	2.5	205	
4-1	22.9	190	14.0	100	
4-2	17.8	265	11.4	295	
4-3	5.1	255	15.2	225	
4-4	7.6	135	31.8	185	Fracture zone through ball locations. Disruption zone between 4-4 and 4-5.
4-5	19.1	295	7.6	225	
4-6	6.3	275	12.7	290	
4-7	8.9	240	14.0	90	Fracture zone through ball locations, heading 210°.
4-8	6.3	215	0.0	0	
4-9	24.1	175	6.3	290	Small scarp between 4-9 and 4-10, rocks overturned.
4-10	8.9	290	11.4	255	Some cracking, disruption zone between 4-10 and 4-11; some cracking.
4-11	10.2	225	12.7	5	Reactivation of major fracture just west of SIGs, heading 350°-0°; second fracture 10 m west.
4-12	15.2	310	6.3	310	Balls moved downslope.
5-1	175.3255		15.2	240	Balls moved downslope.
5-2	15.2	310	0.0	0	Balls moved downslope.
5-3	14.0	265	6.3	245	
5-4	0.0	0	0.0	0	
5-5	10.2	320	0.0	0	
5-6	0.0	0	0.0	0	

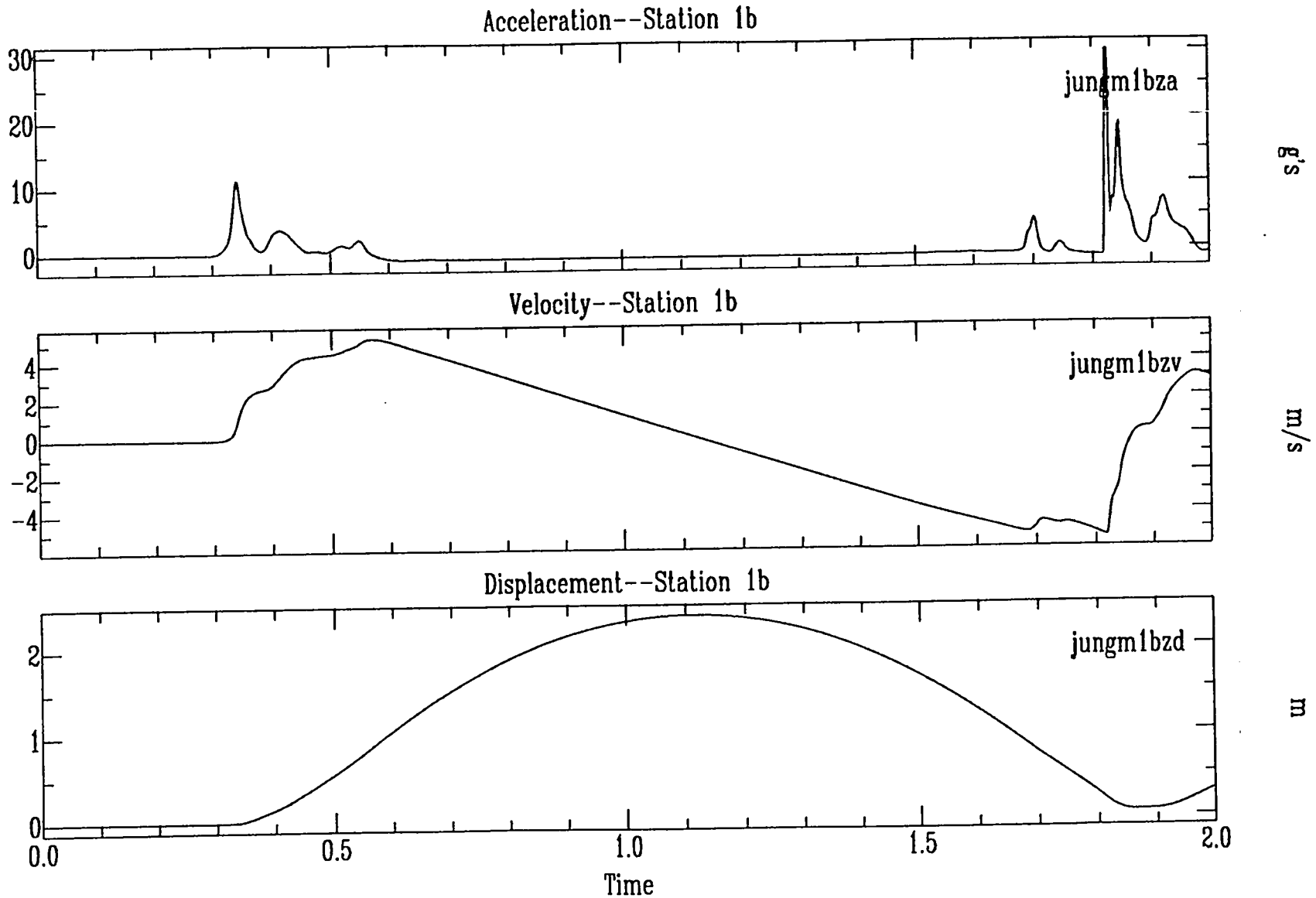
Table 16. Junction SIG Results (Concluded)

Location	Golf Ball Dist (cm)	Golf Ball Azi	Steel Ball Dist (cm)	Steel Ball Azi	Comment
5-7	0.0	0	0.0	0	
5-8	7.6	110	6.3	270	
6-1	27.9	285	31.8	235	Balls moved downslope.
6-2	27.9	270	24.1	260	Balls moved downslope.
6-3	12.7	180	24.1	90	Steel ball moved upslope, stopped in a depression.
6-4	12.7	180	24.1	275	Fracture zone between 6-3 and 6-4.
6-5	21.6	165	17.8	125	Fracture zone between 6-4 and 6-5, 20m west of 6-4.
6-6	5.1	105	6.3	35	
6-7	8.9	220	5.1	265	
6-8	14.0	140	10.2	95	
6-9	****	***	0.0	0	
6-10	7.6	120	3.8	275	
6-11	0.0	0	0.0	0	
6-12	7.6	105	0.0	0	
6-13	12.7	310	7.6	345	
6-14	2.5	300	6.3	145	Golf ball moved upslope.
6-15	7.6	40	5.1	115	
6-16	20.3	15	6.3	115	
7-1	14.0	275	8.9	140	
7-2	14.0	285	0.0	0	
7-3	0.0	0	0.0	0	
7-4	8.9	165	2.5	70	
7-5	6.3	255	0.0	0	
7-6	2.5	290	7.6	305	
7-7	7.6	65	0.0	0	
7-8	5.1	345	0.0	0	
7-9	11.4	130	0.0	0	
7-10	0.0	0	0.0	0	

Junction Surface Ground Motion



Junction Surface Ground Motion



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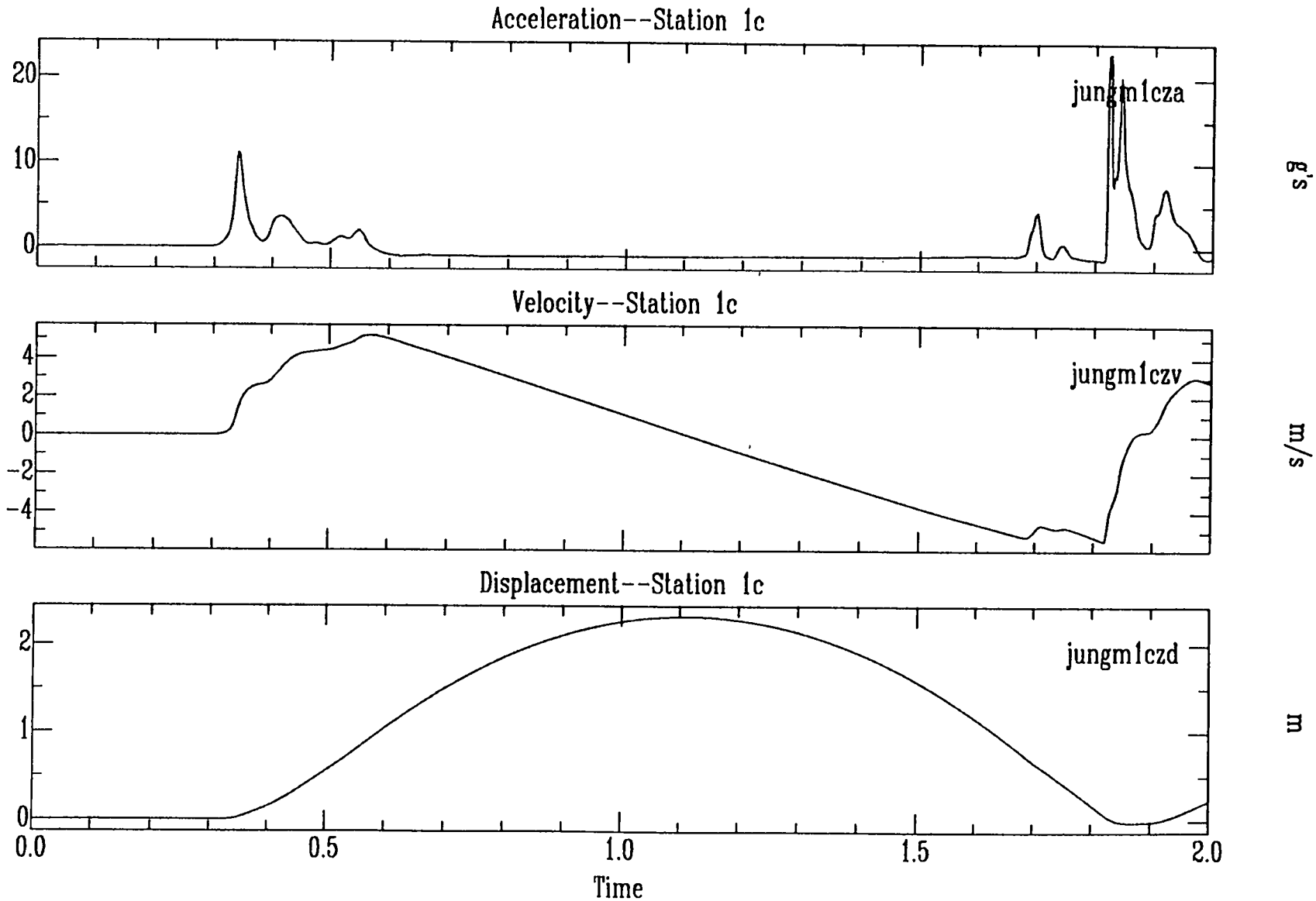

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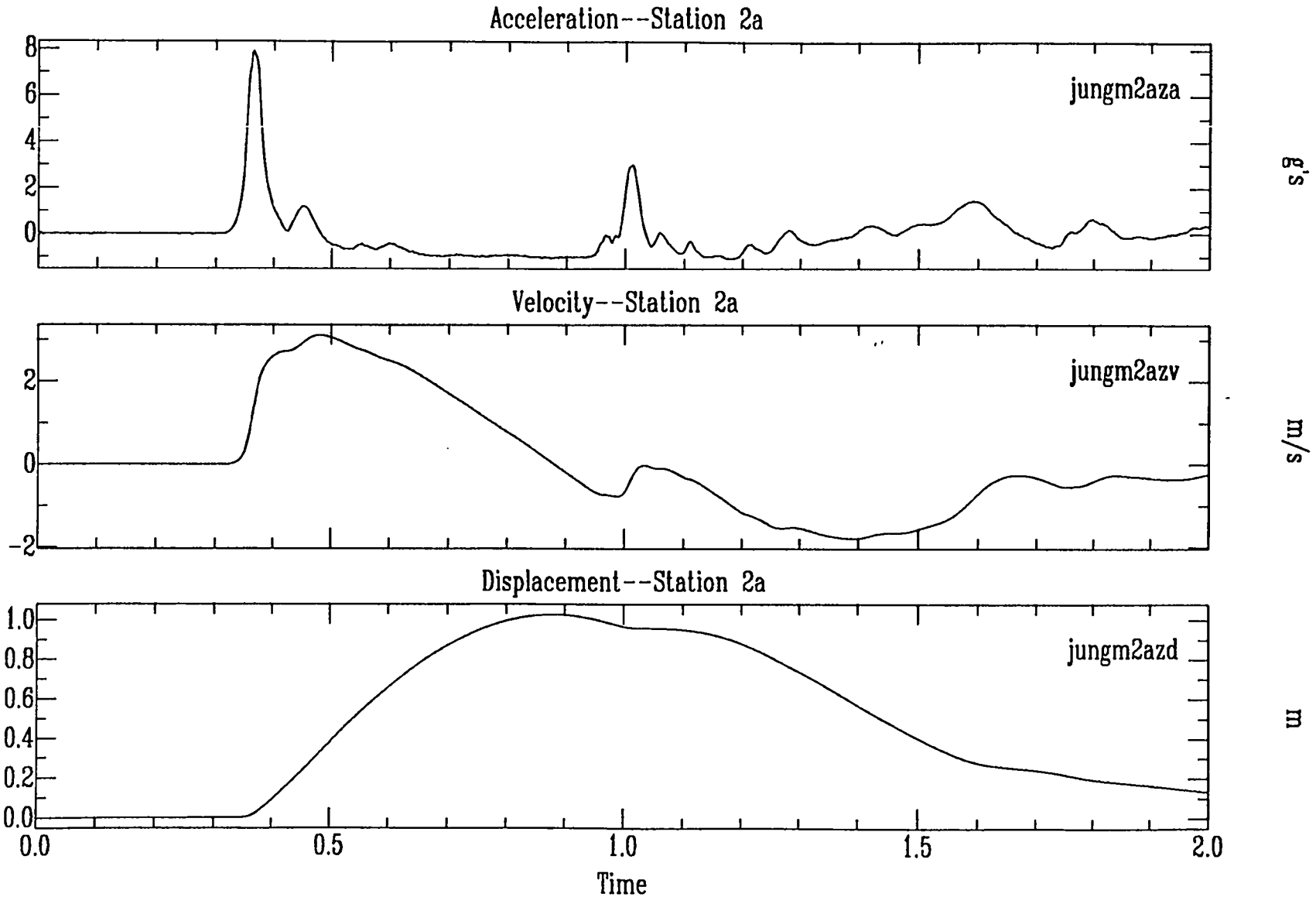

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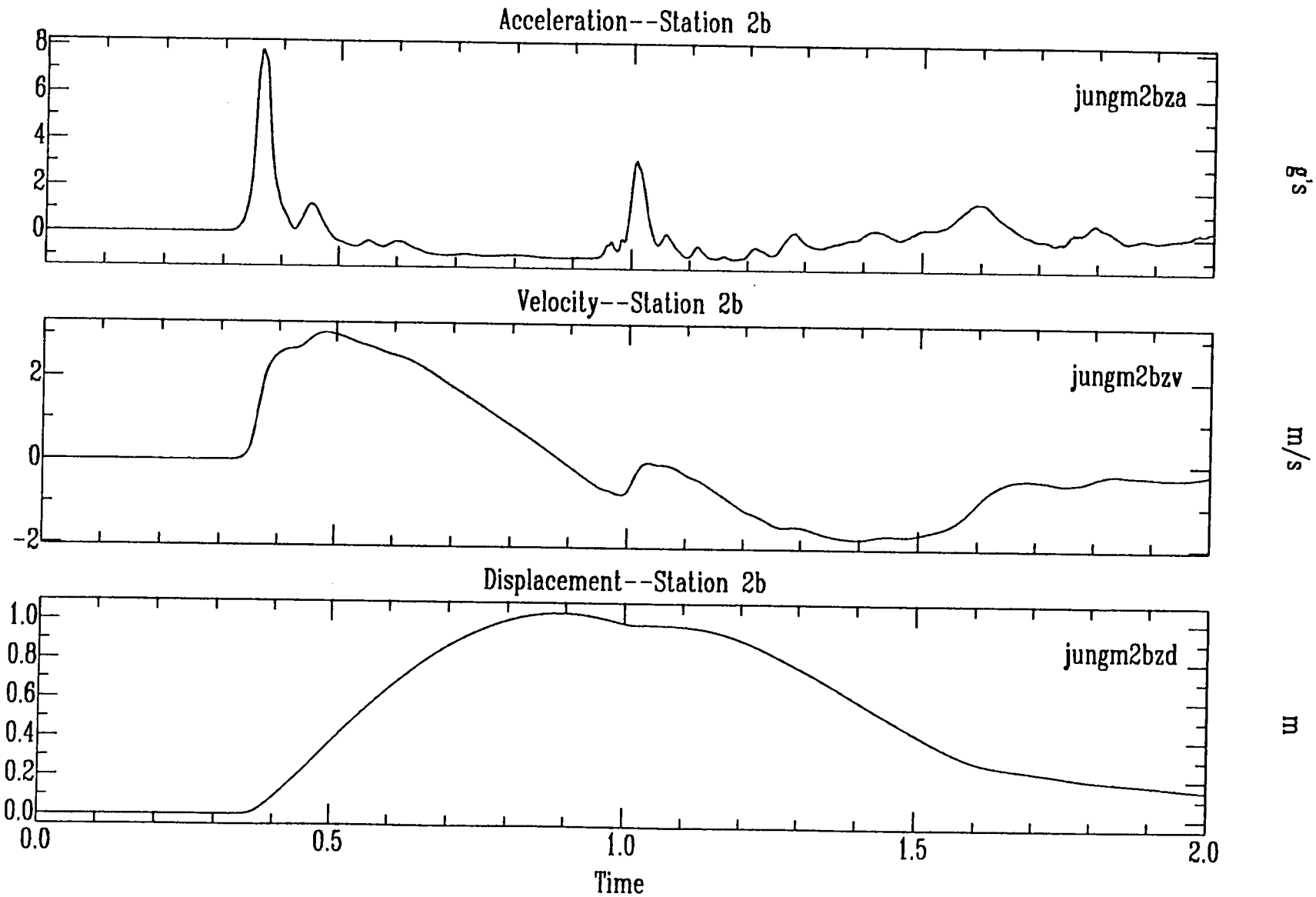

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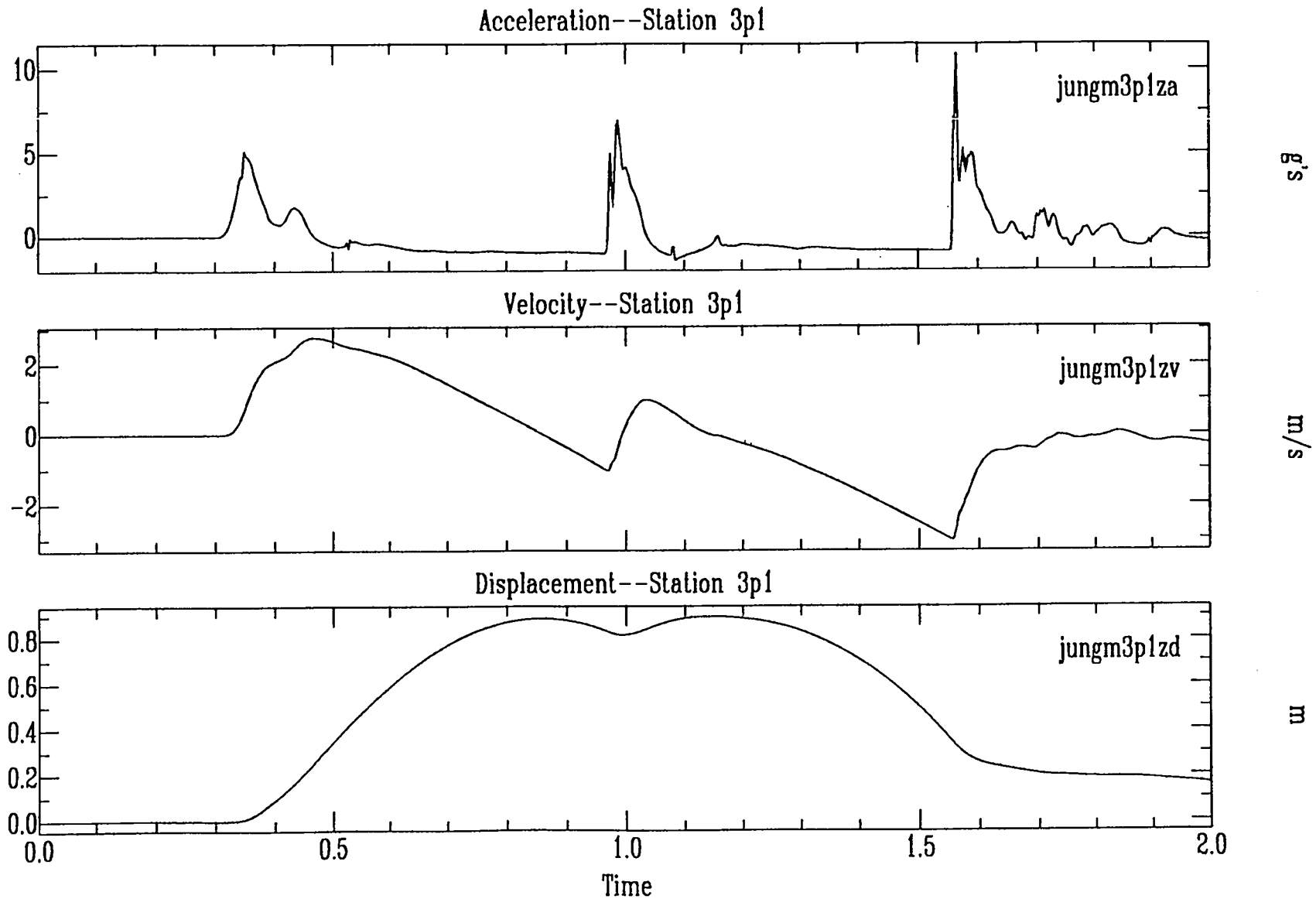

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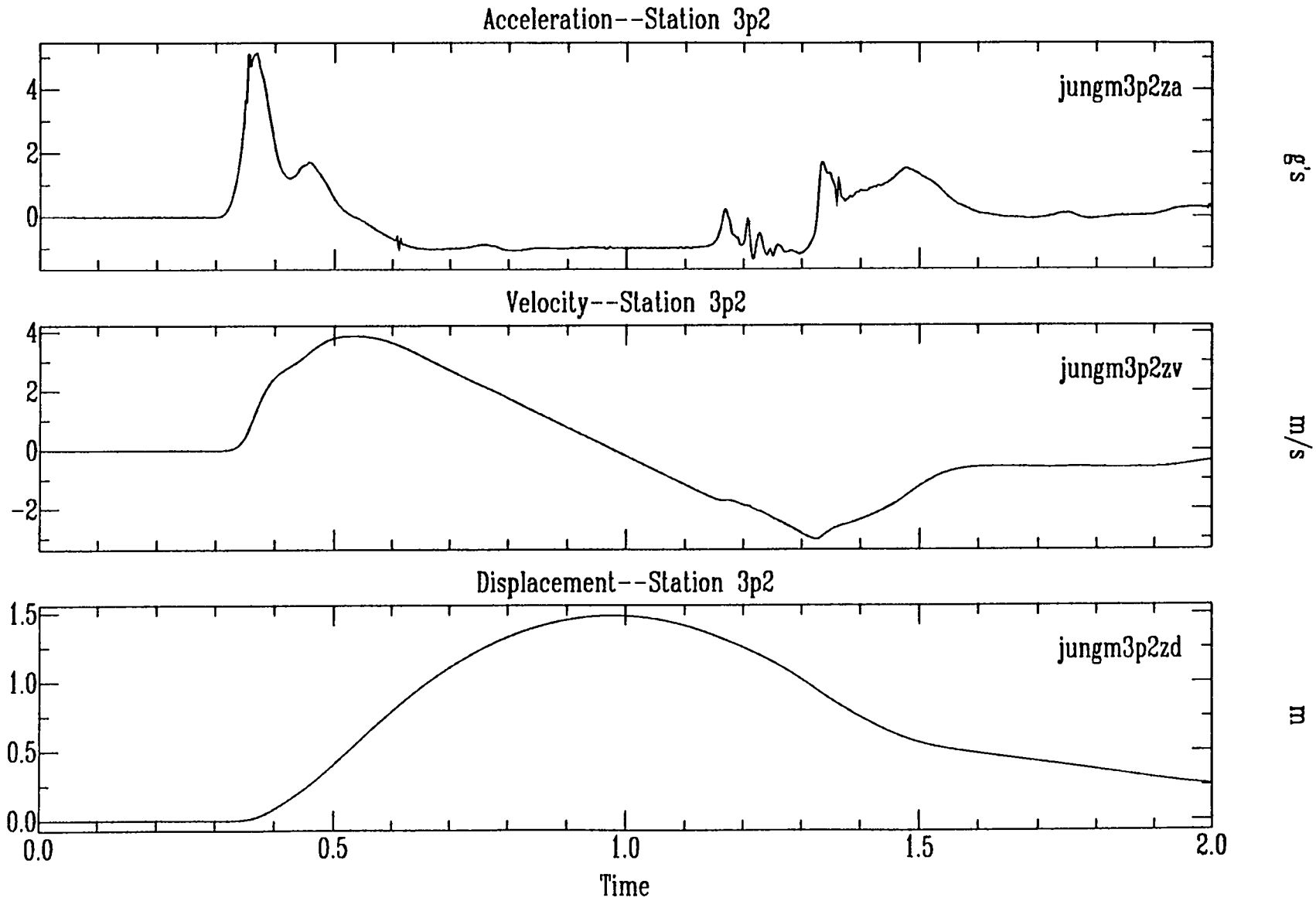

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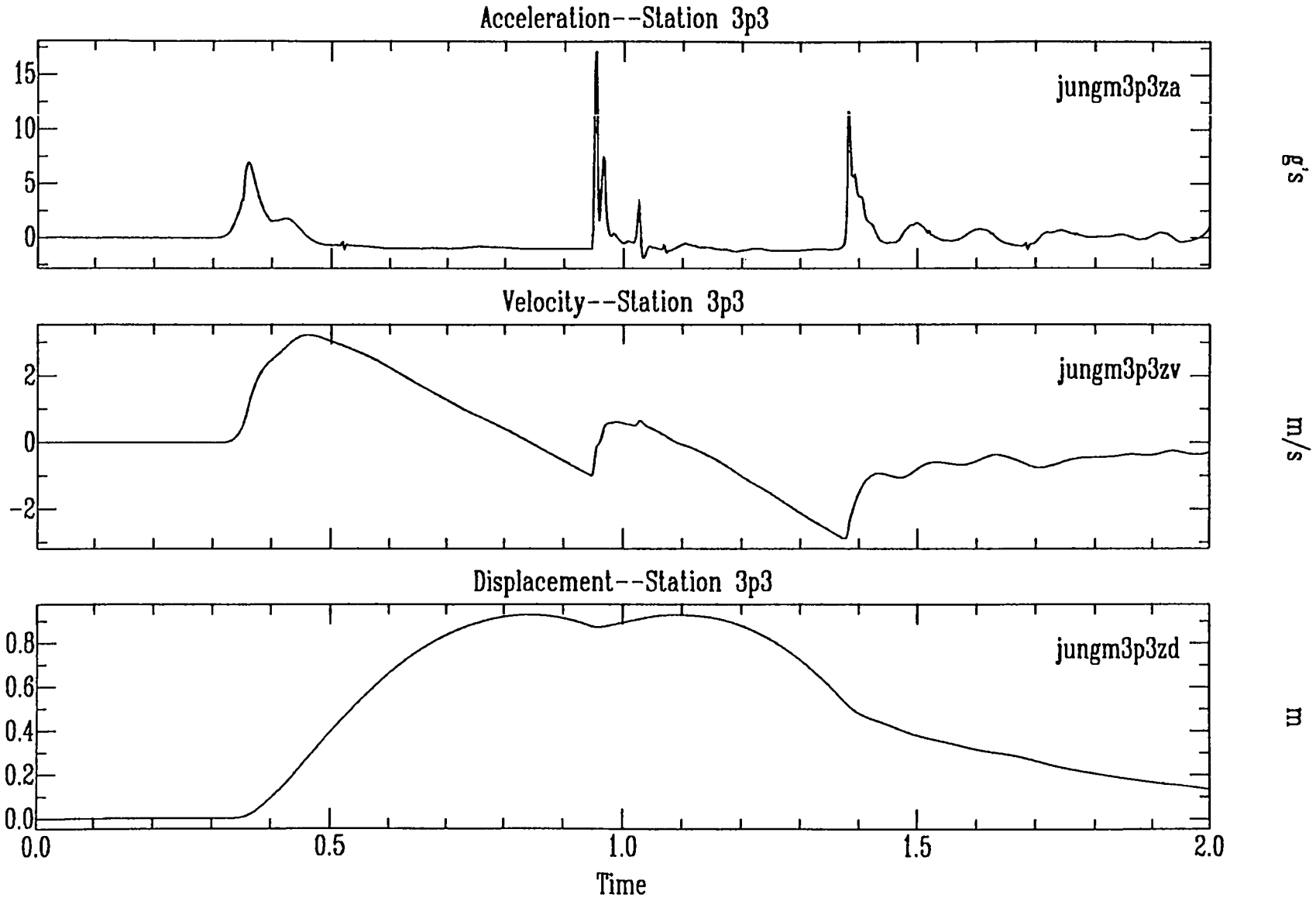
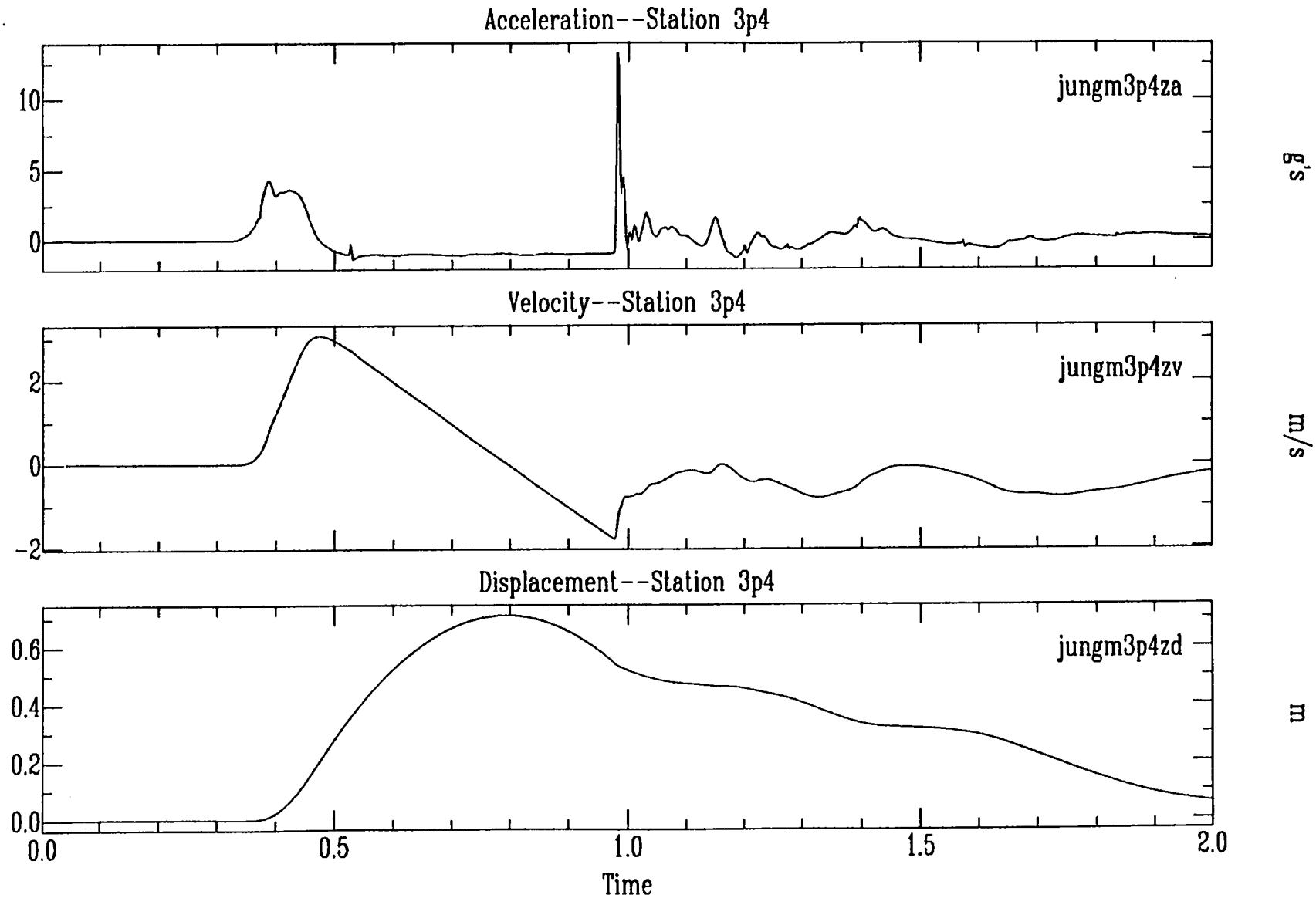


Junction Surface Ground Motion



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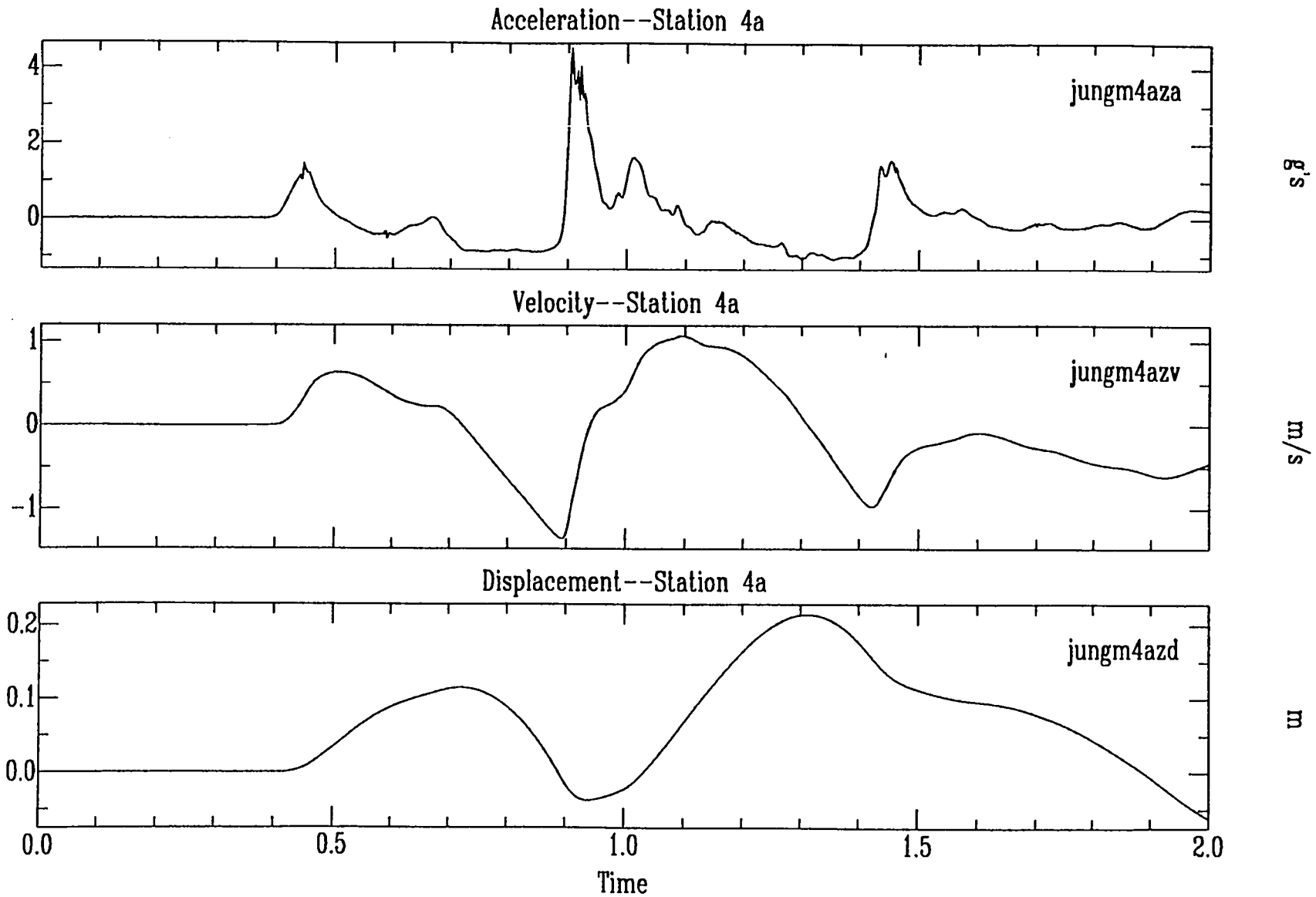

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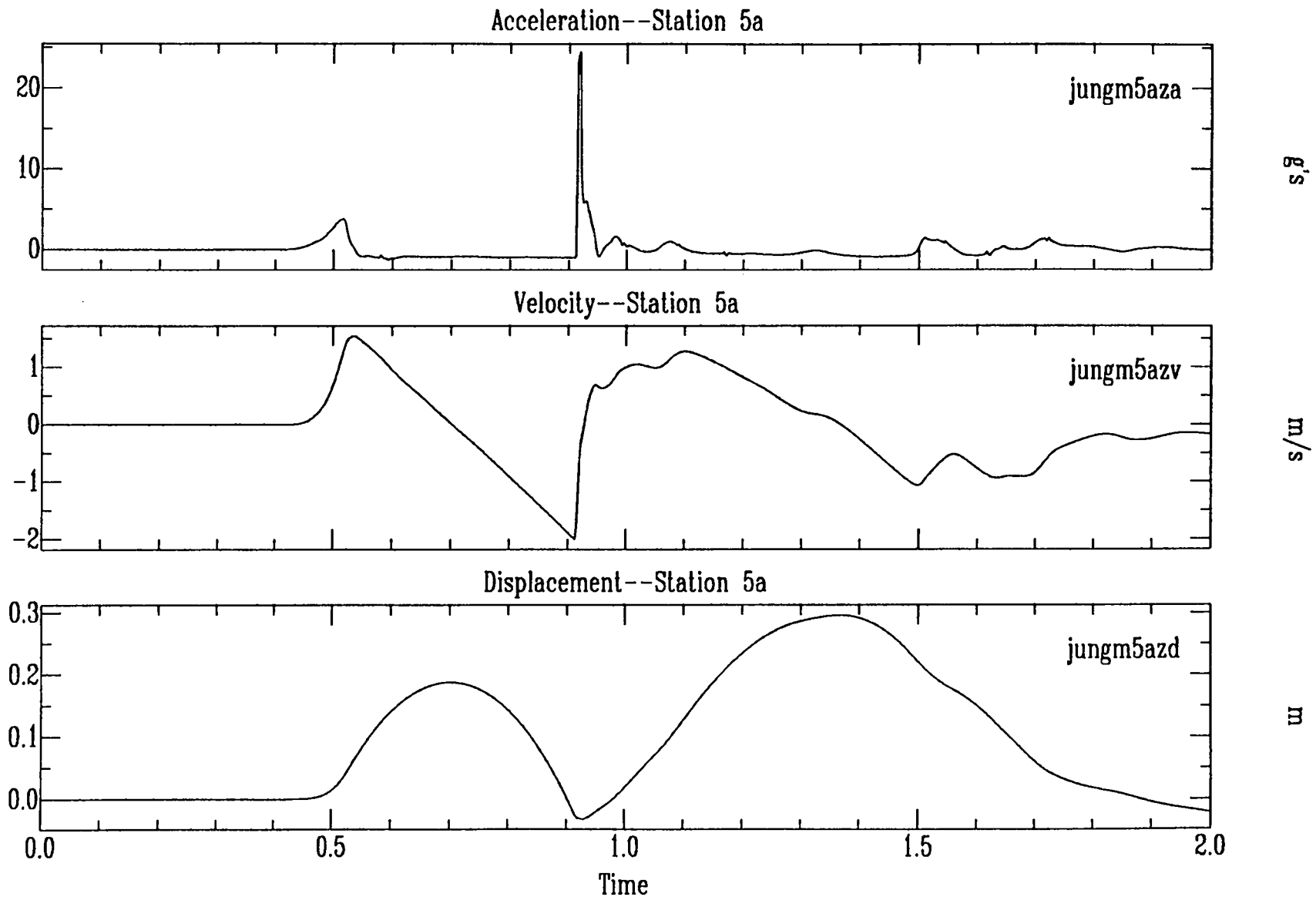

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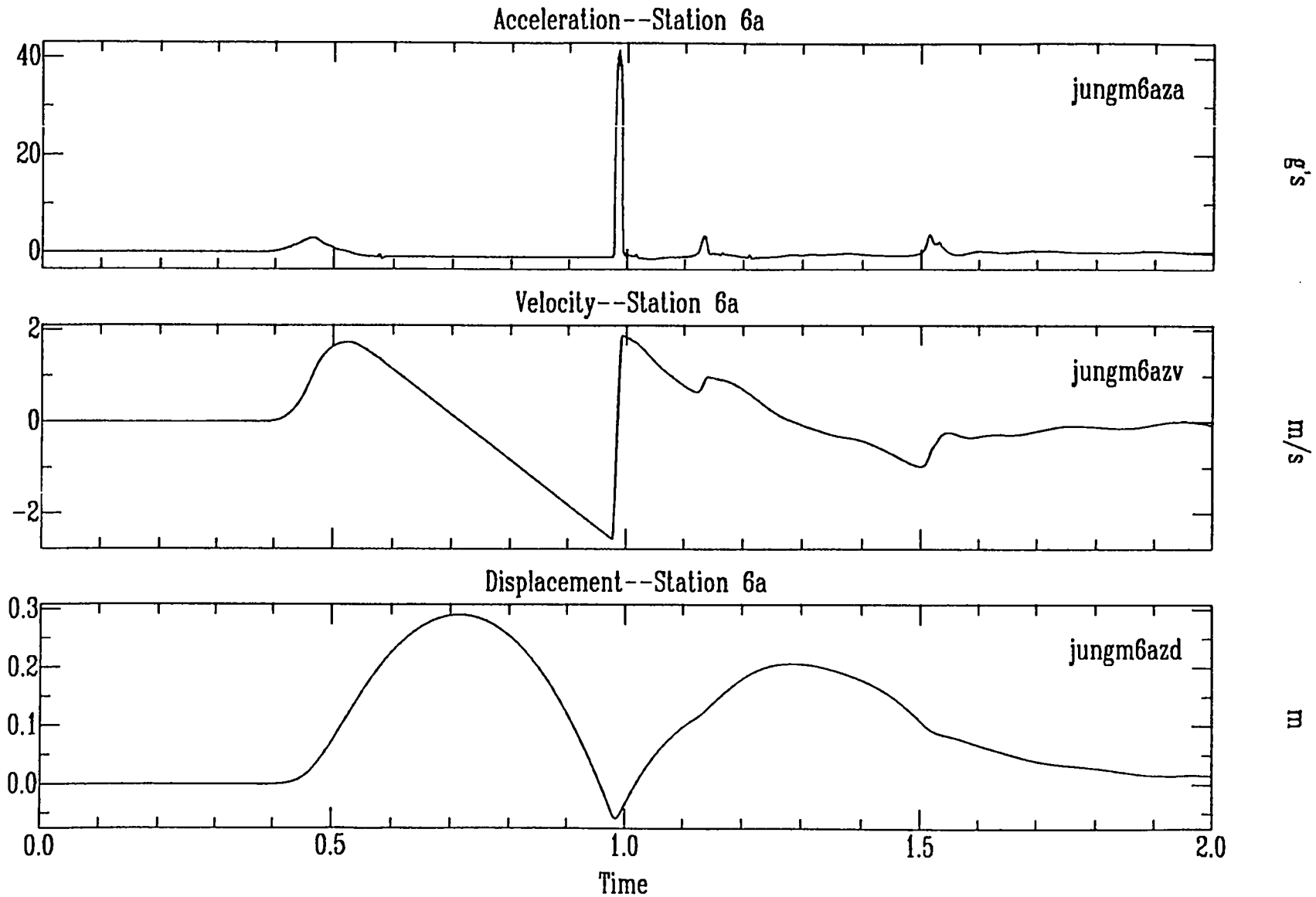

5. Additional Information

These data plus the horizontal and tangential components reside as digital time-series files in the Ground-Motion Database, a GEODES DBMS database on a VAX VMS minicomputer. The vertical data presented herein also reside as Seismic Analysis Code (SAC) from Lawrence Livermore National Laboratory files on a Sun workstation. For additional information regarding these data sets you may contact:

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