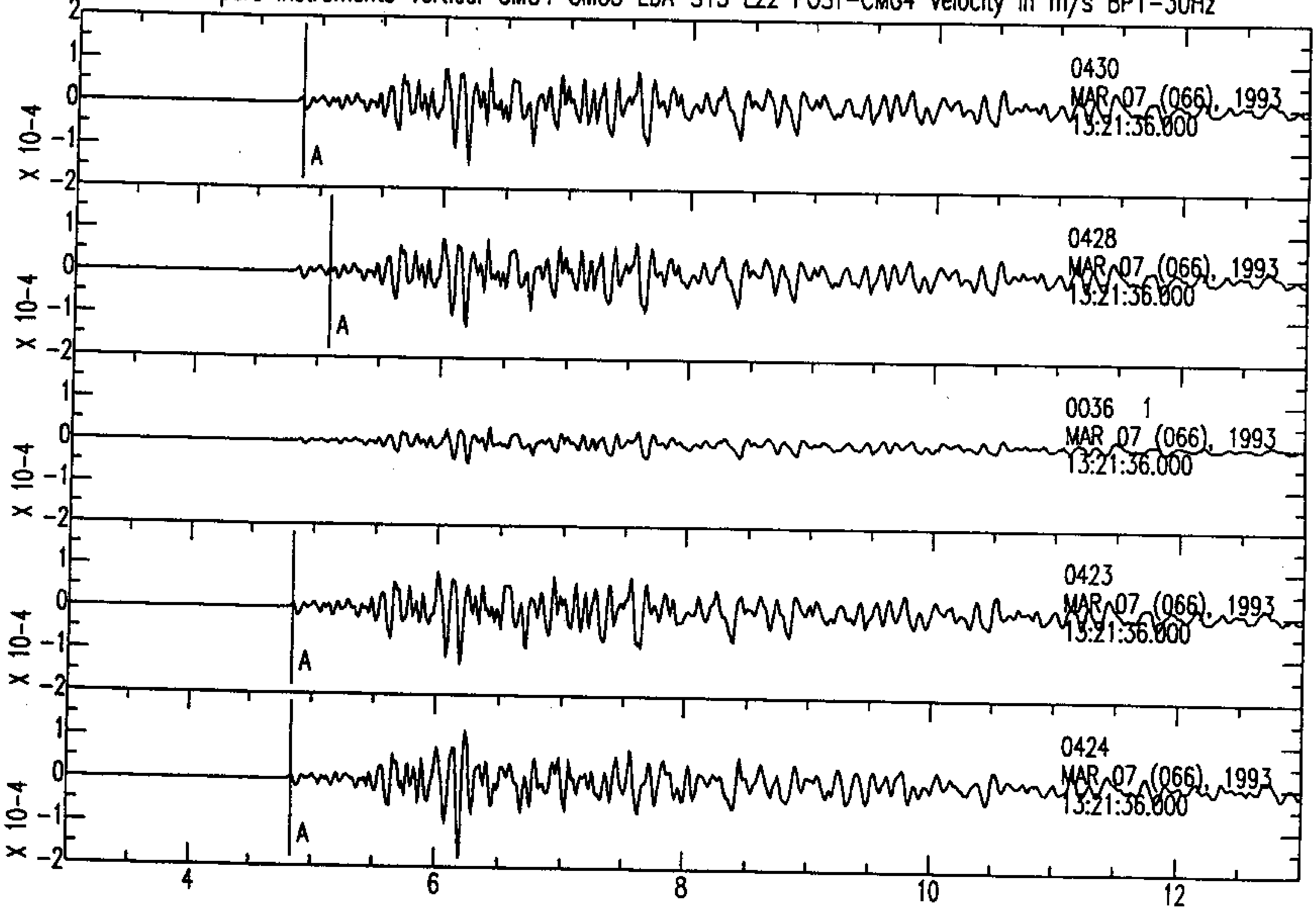
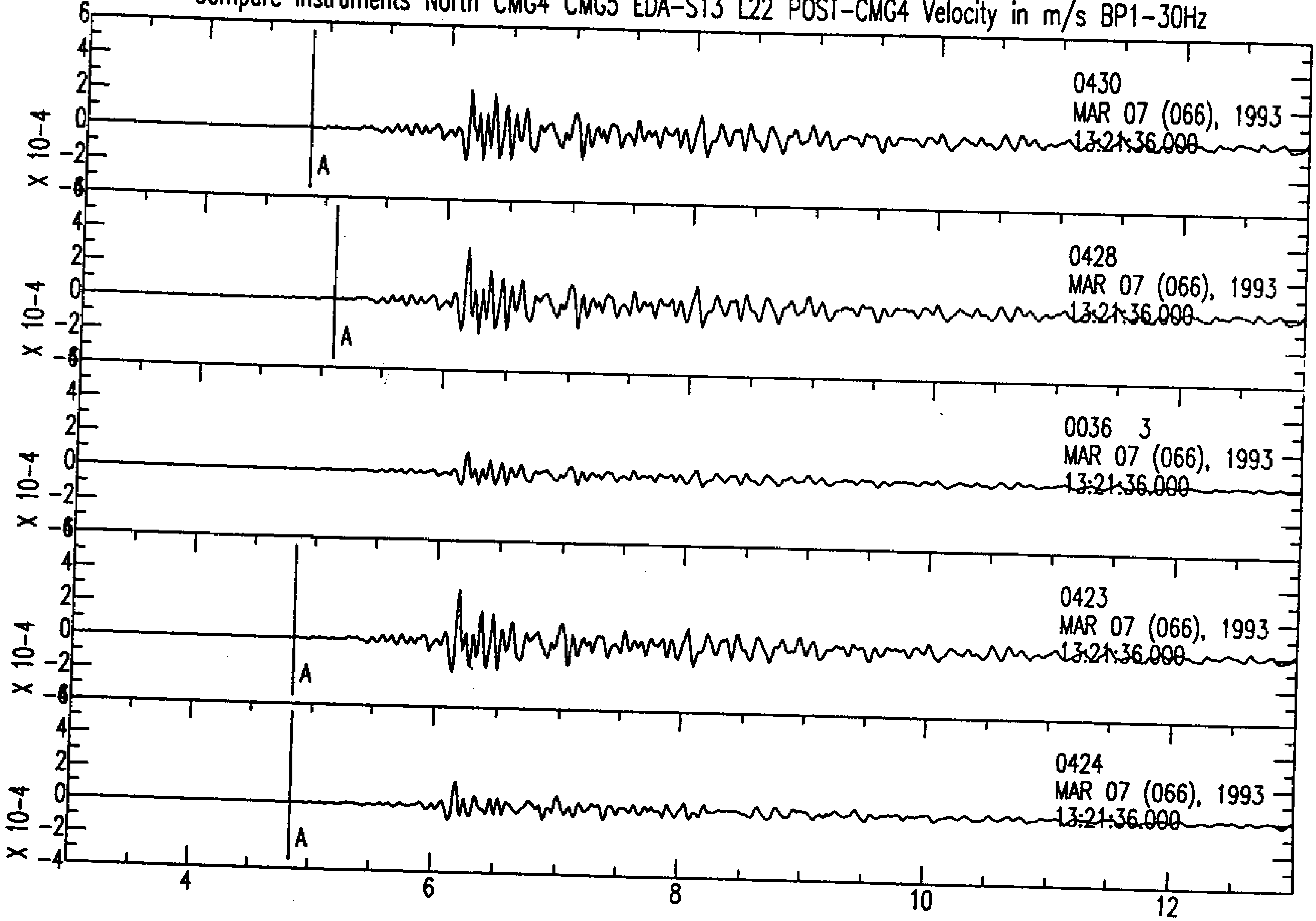
III-C. Cluster test seismograms.

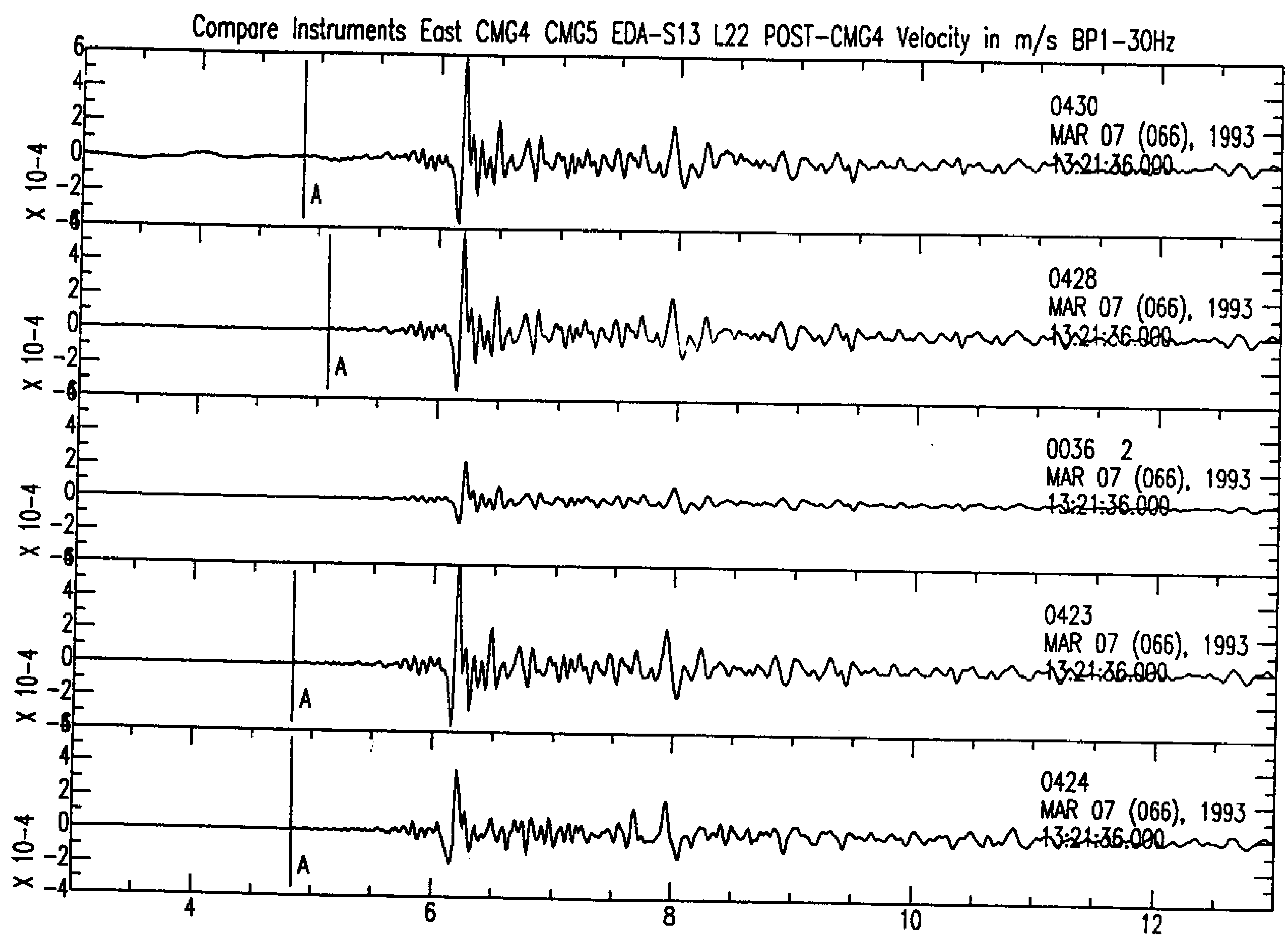
Sample cluster test seismograms from each type of instrument used in the deployment as well as a posthole CMG4. The instrument response (Table III-D and Section V-C, for EDAs) as provided by the factory has been removed from each instrument, and they are all convolved with a generic velocity response. A bandpass filter from 1 to 30 Hz has been applied. In order from top to bottom, the instruments are: CMG4, CMG5, S13 seismometer hooked to an EDA instrument, L22, and posthole CMG4 with 30 sec response. Separate figures display the vertical, north, and east seismograms. Note that there is good phase agreement between all the seismometers used in the experiment, but that amplitudes for the EDA/S13 combination are about a factor of two too low for all components, and the posthole CMG4, which was not used in the experiment, has phase and amplitude different in the north and east component.

Compare Instruments Vertical CMG4 CMG5 EDA-S13 L22 POST-CMG4 Velocity in m/s BP1-30Hz



Compare Instruments North CMG4 CMG5 EDA-S13 L22 POST-CMG4 Velocity in m/s BP1-30Hz

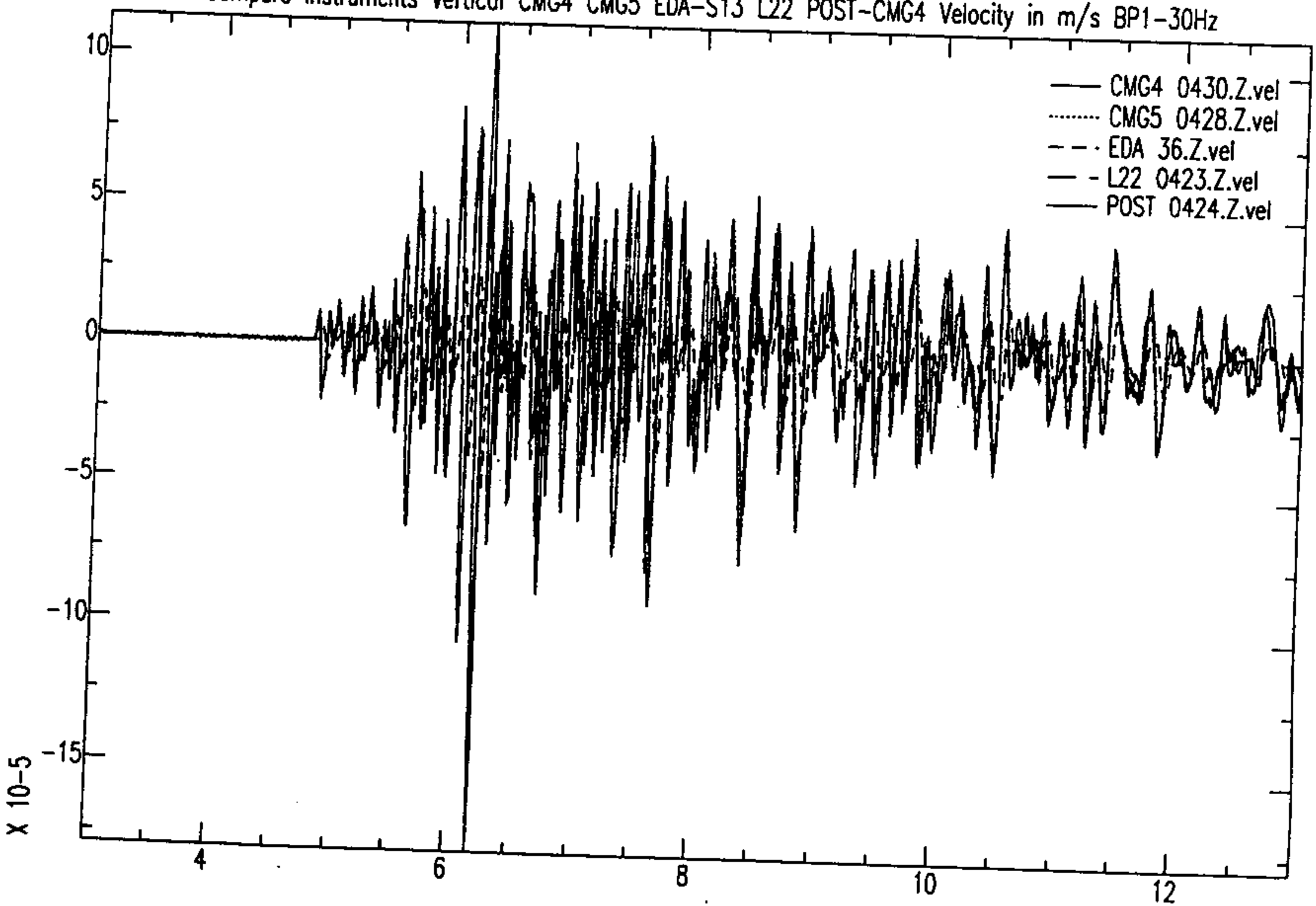


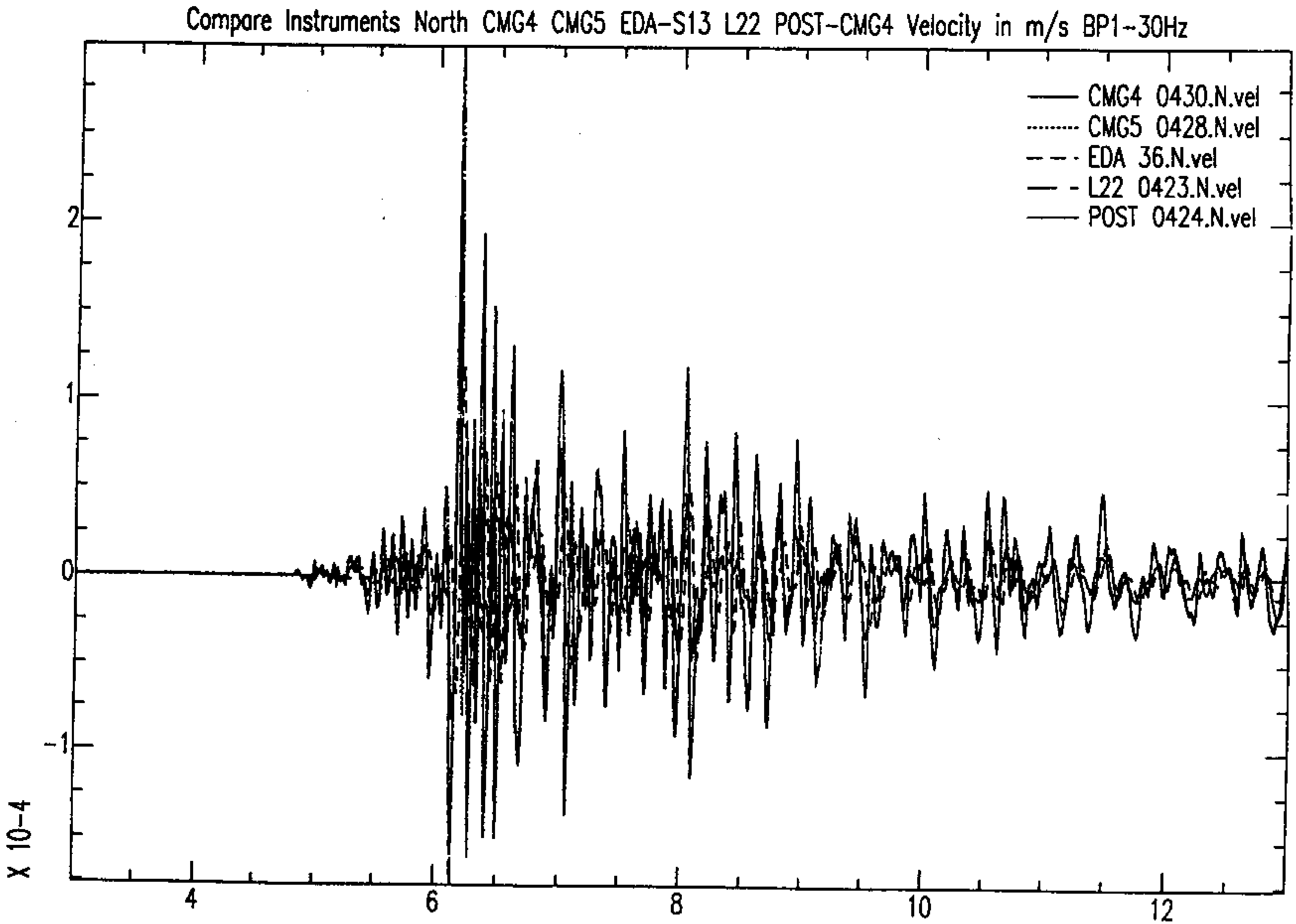


Compare Instruments East CMG4 CMG5 EDA-S13 L22 POST-CMG4 Velocity in m/s BP1-30Hz
0430
MAR 07 (066), 1993
13:21:36.000
0428
MAR 07 (066), 1993
13:21:36.000
0036 2
MAR 07 (066), 1993
13:21:36.000
0423
MAR 07 (066), 1993
13:21:36.000
0424
MAR 07 (066), 1993
13:21:36.000
X 10-4
A
4
6
8
10
12

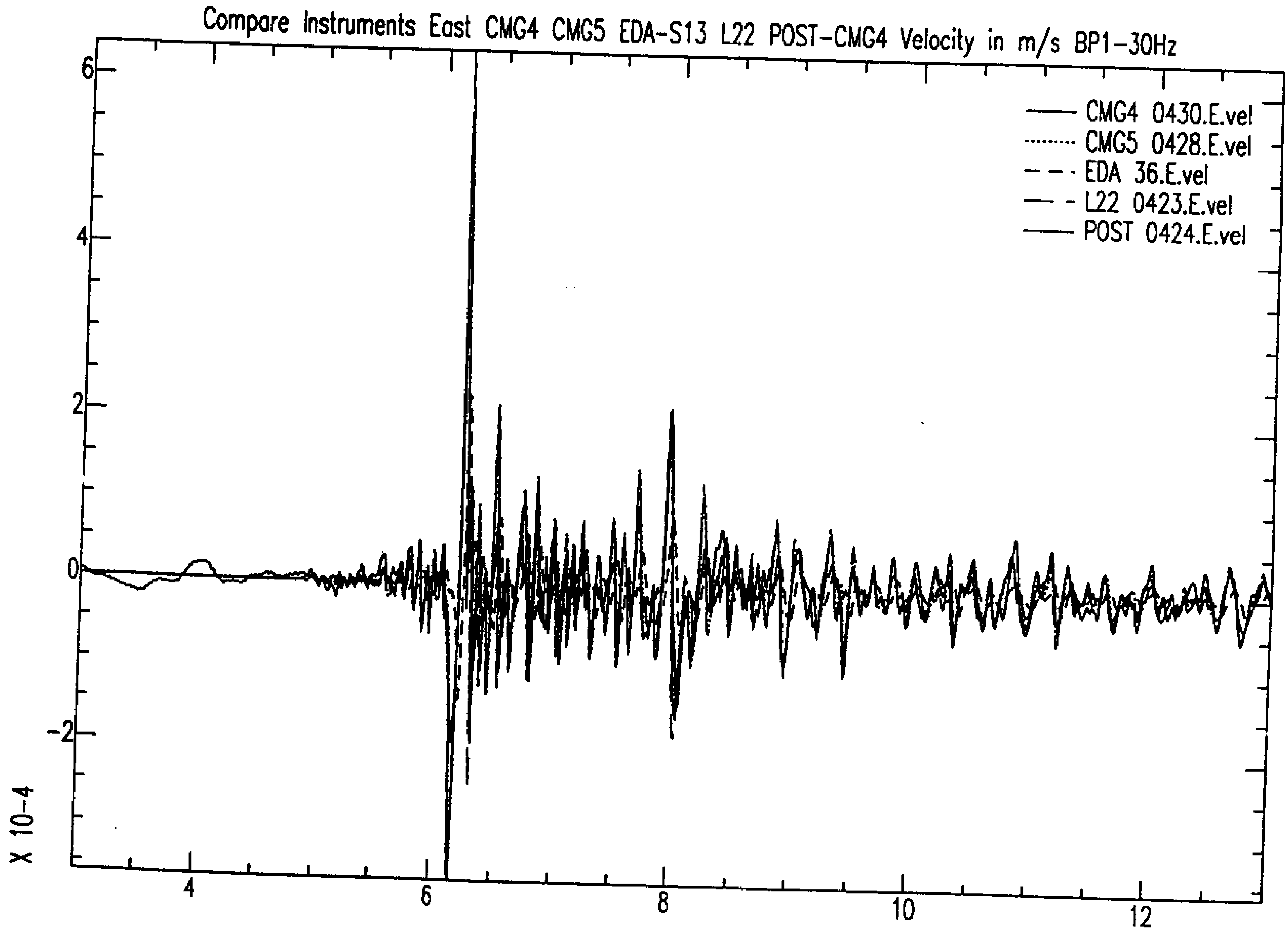
Same as previous figure, with seismograms now overlain. This emphasizes the difference in seismogram amplitudes.

Compare Instruments Vertical CMG4 CMG5 EDA-S13 L22 POST-CMG4 Velocity in m/s BP1-30Hz



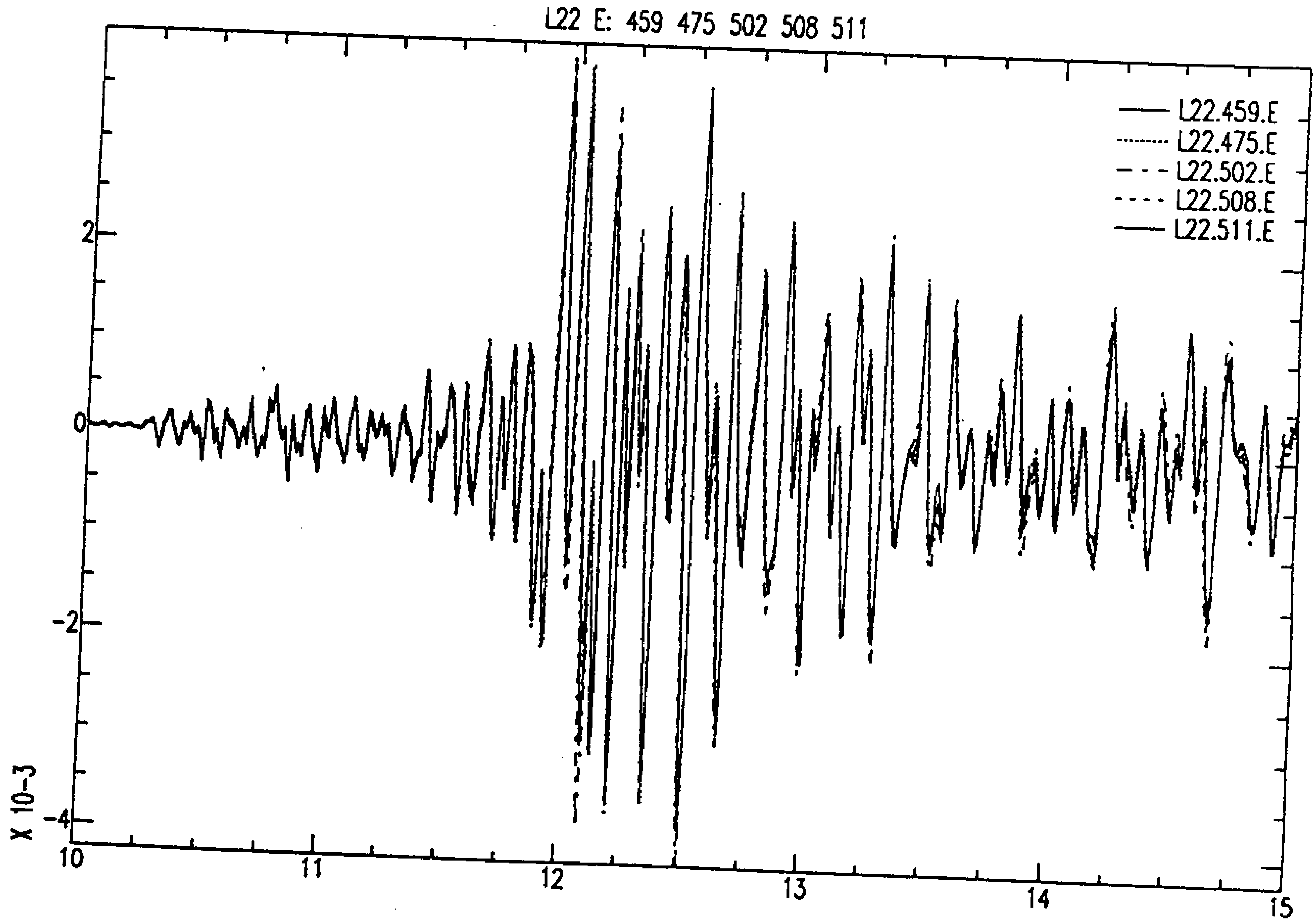


Compare Instruments North CMG4 CMG5 EDA-S13 L22 POST-CMG4 Velocity in m/s BP1-30Hz
CMG4 0430.N.vel
CMG5 0428.N.vel
EDA 36.N.vel
L22 0423.N.vel
POST 0424.N.vel
2
1
0
-1
X 10-4
4
6
8
10
12



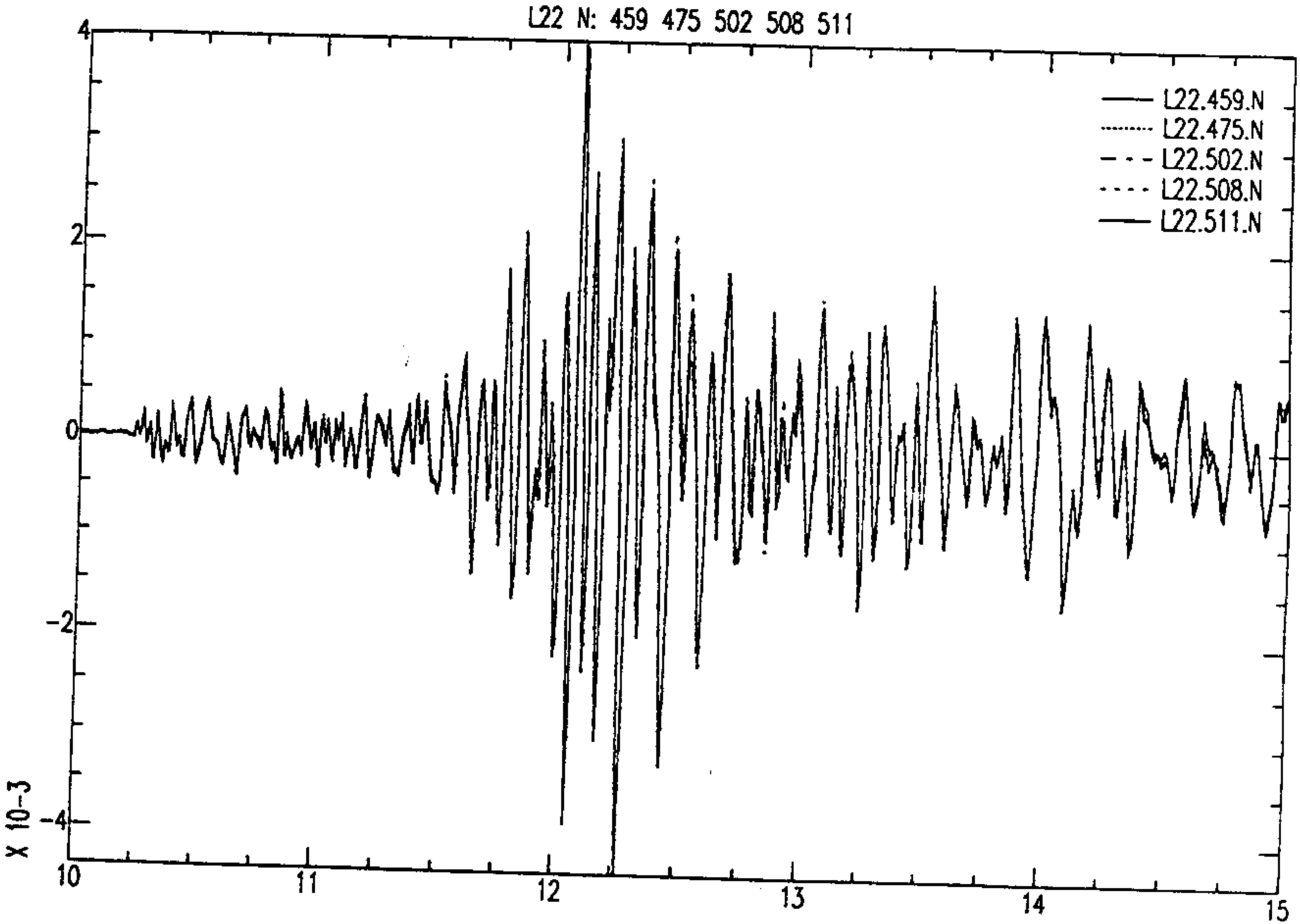
Compare Instruments East CMG4 CMG5 EDA-S13 L22 POST-CMG4 Velocity in m/s BP1-30Hz
CMG4 0430.E.vel
CMG5 0428.E.vel
EDA 36.E.vel
L22 0423.E.vel
POST 0424.E.vel
6
4
2
0
-2
X 10-4
4
6
8
10
12

L22 East component seismograms overlain. Numbers correspond to the serial numbers of the five different L22 sensors compared.



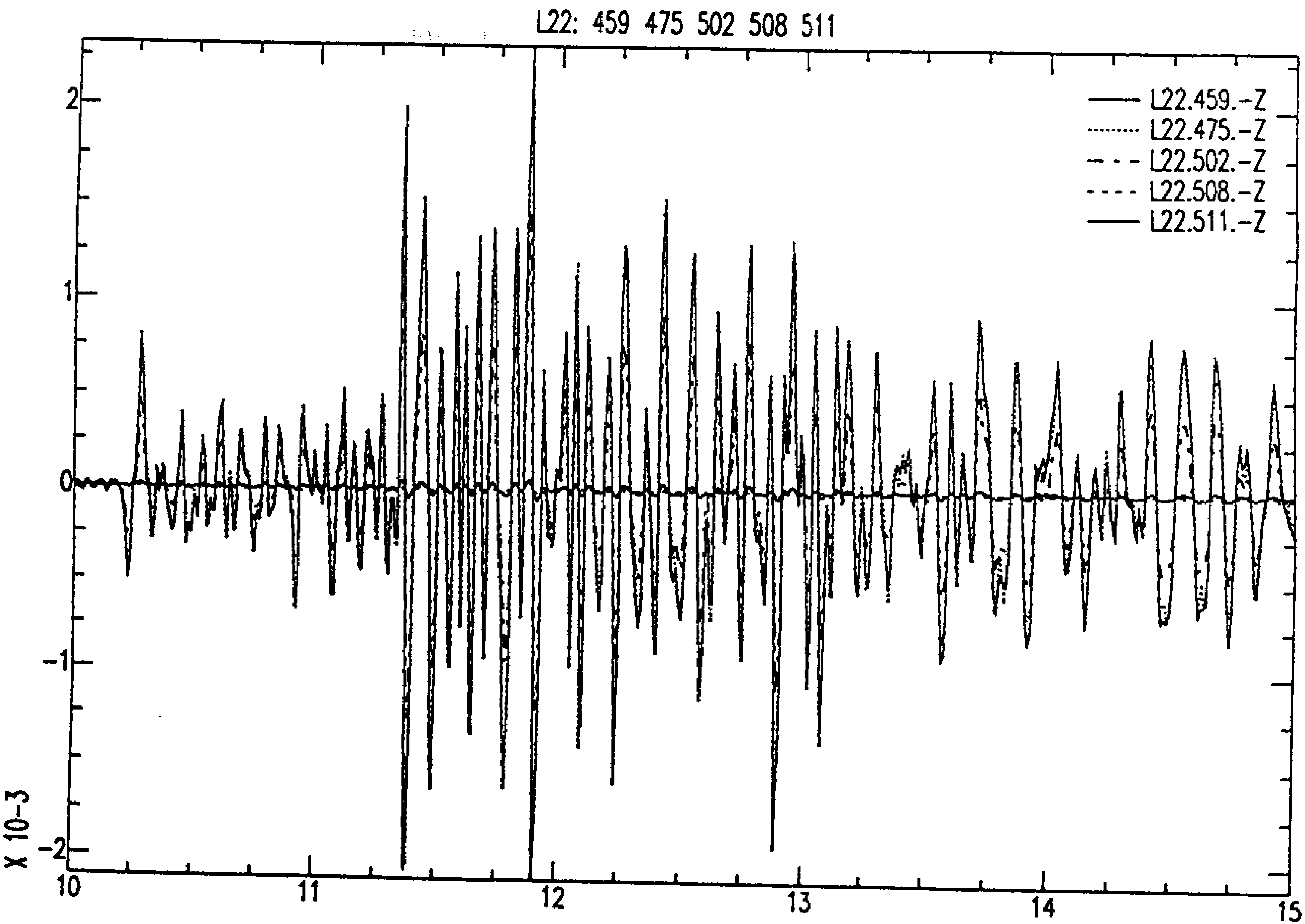
L22 E: 459 475 502 508 511
L22.459.E
L22.475.E
L22.502.E
L22.508.E
L22.511.E
2
0
-2
-4
X 10-3
10
11
12
13
14
15

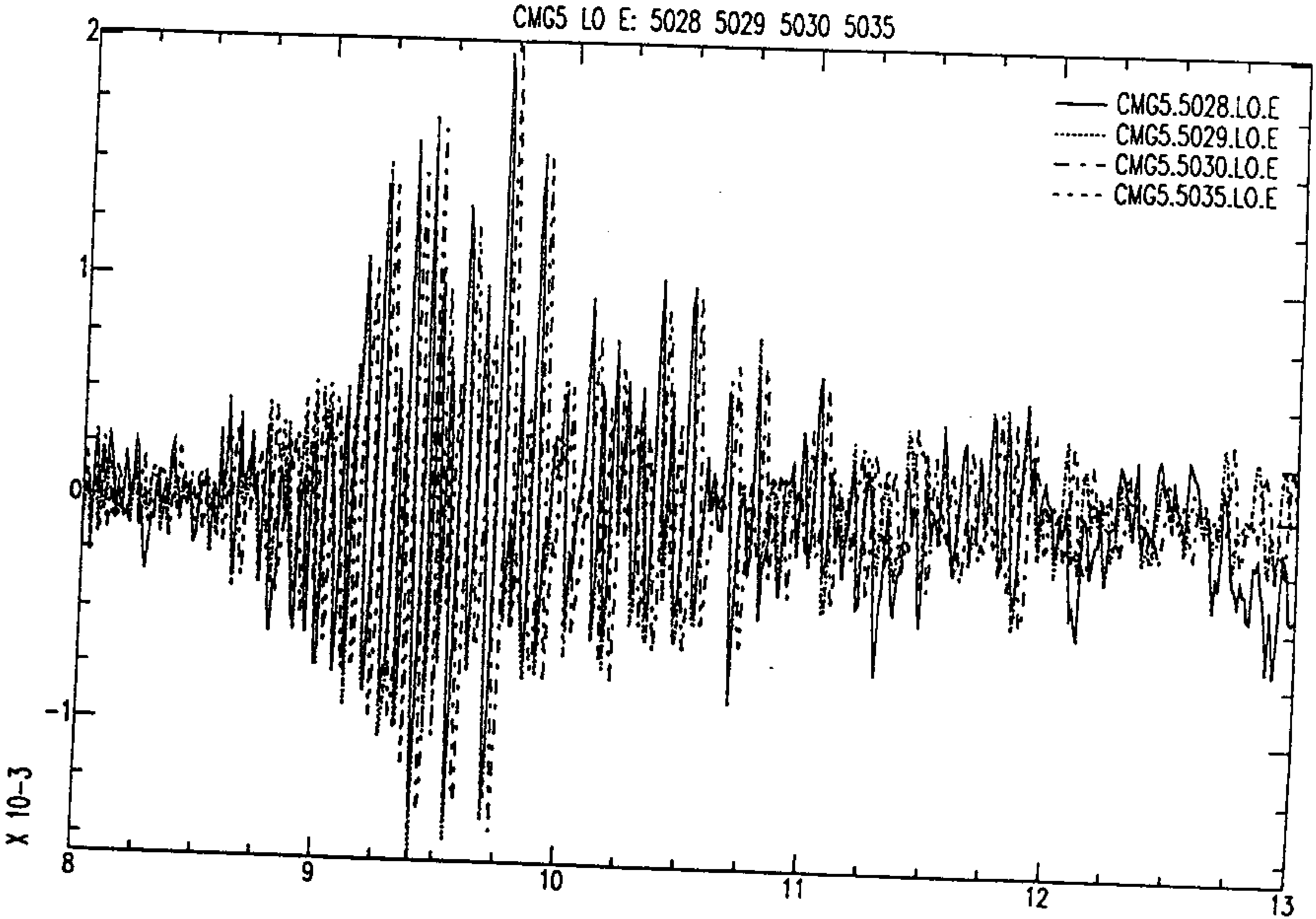
L22 North component seismograms overlain.

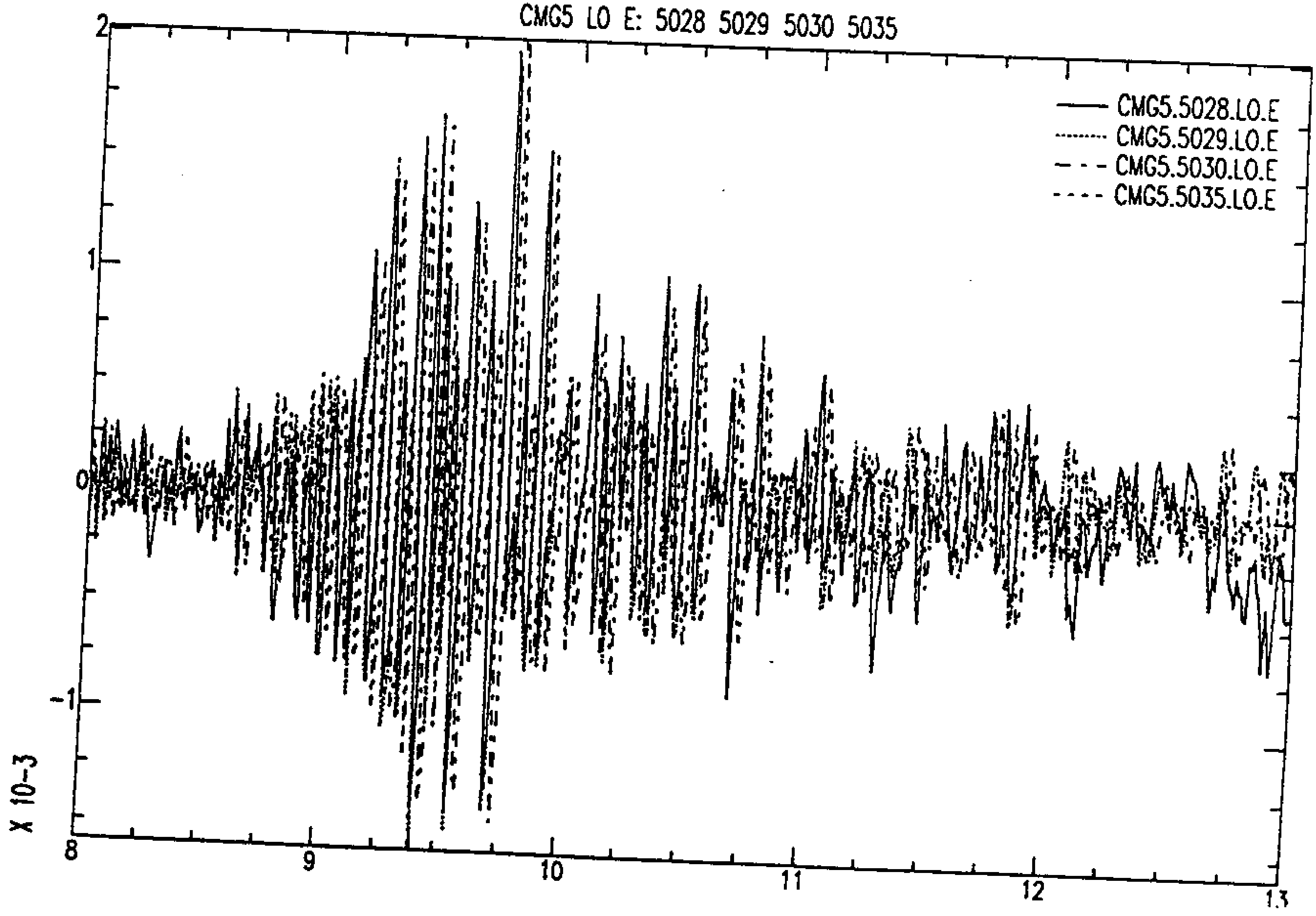

L22 N: 459 475 502 508 511
L22.459.N
L22.475.N
L22.502.N
L22.508.N
L22.511.N
X 10-3
4
2
0
-2
-4
10
11
12
13
14
15

L22 Vertical component seismograms overlain. Note reduced amplitudes of two of the L22's. This problem existed in the cluster test but not in the aftershock deployment and is not fully understood. It is likely a problem with the Reftek software rather than a problem with the seismometer.

z

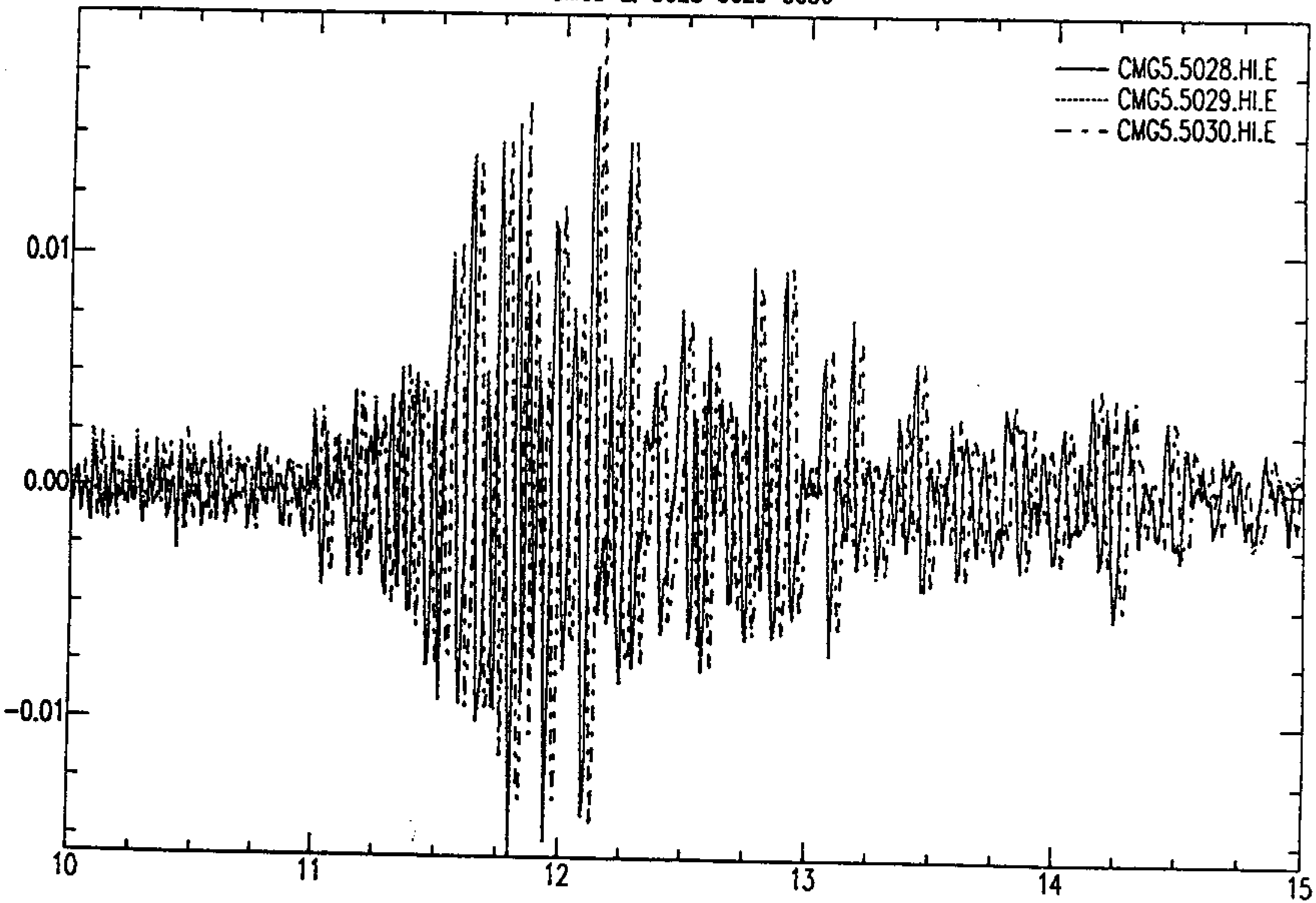

L22: 459 475 502 508 511
L22.459.-Z
L22.475.-Z
L22.502.-Z
L22.508.-Z
L22.511.-Z
X 10-3
2
1
0
-1
-2
10
11
12
13
14
15


CMG5 LO E: 5028 5029 5030 5035
CMG5.5028.LO.E
CMG5.5029.LO.E
CMG5.5030.LO.E
CMG5.5035.LO.E
X 10-3
2
1
0
-1
8
9
10
11
12
13

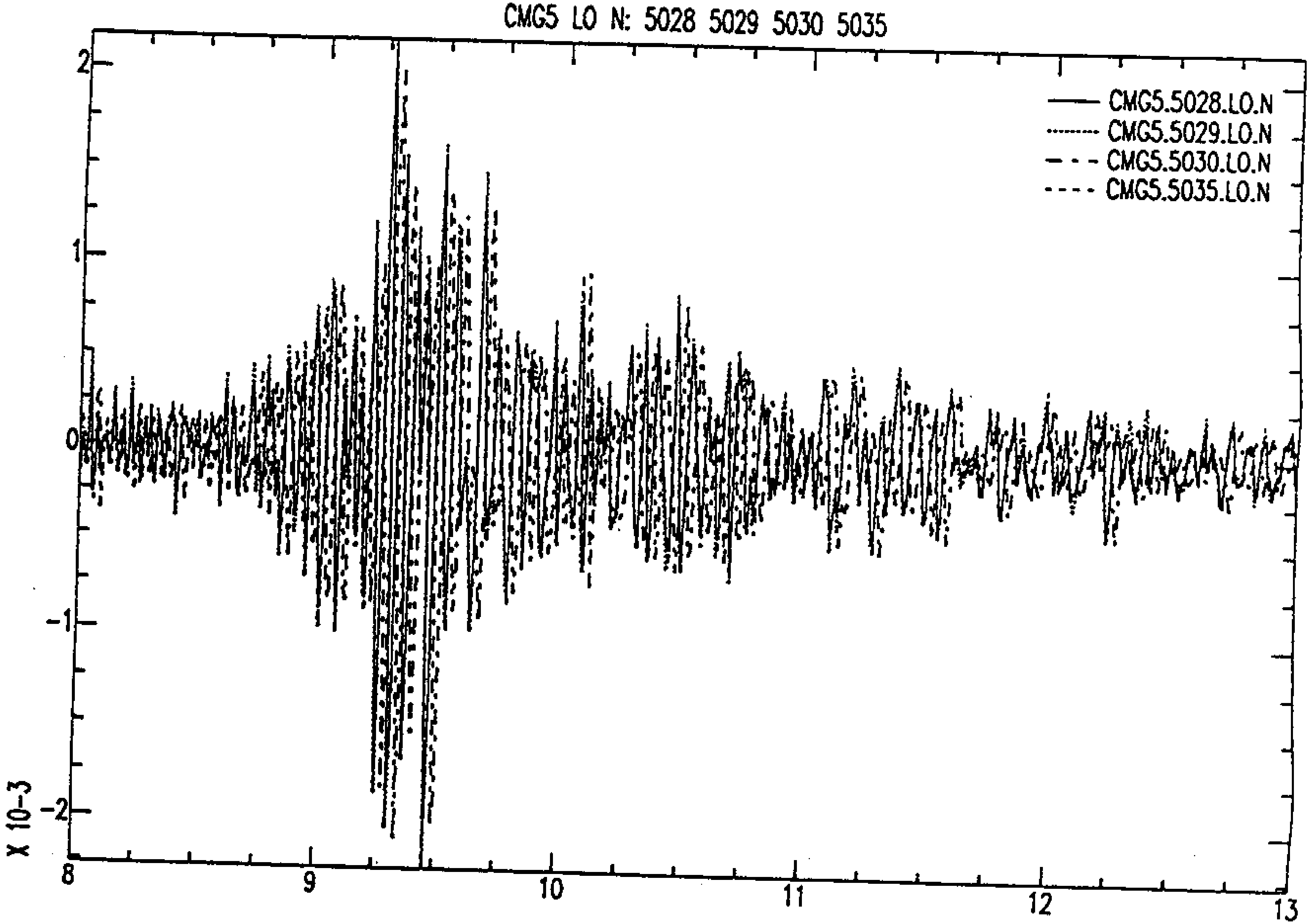

CMG5 LO E: 5028 5029 5030 5035
CMG5.5028.LO.E
CMG5.5029.LO.E
CMG5.5030.LO.E
CMG5.5035.LO.E
X 10-3
2
1
0
-1
8
9
10
11
12
13

CMG5 high gain East component seismograms overlain.
Numbers correspond to the serial numbers of the three different CMG5 high gain seismograms compared.

hi-gain
CMG5 E: 5028 5029 5030



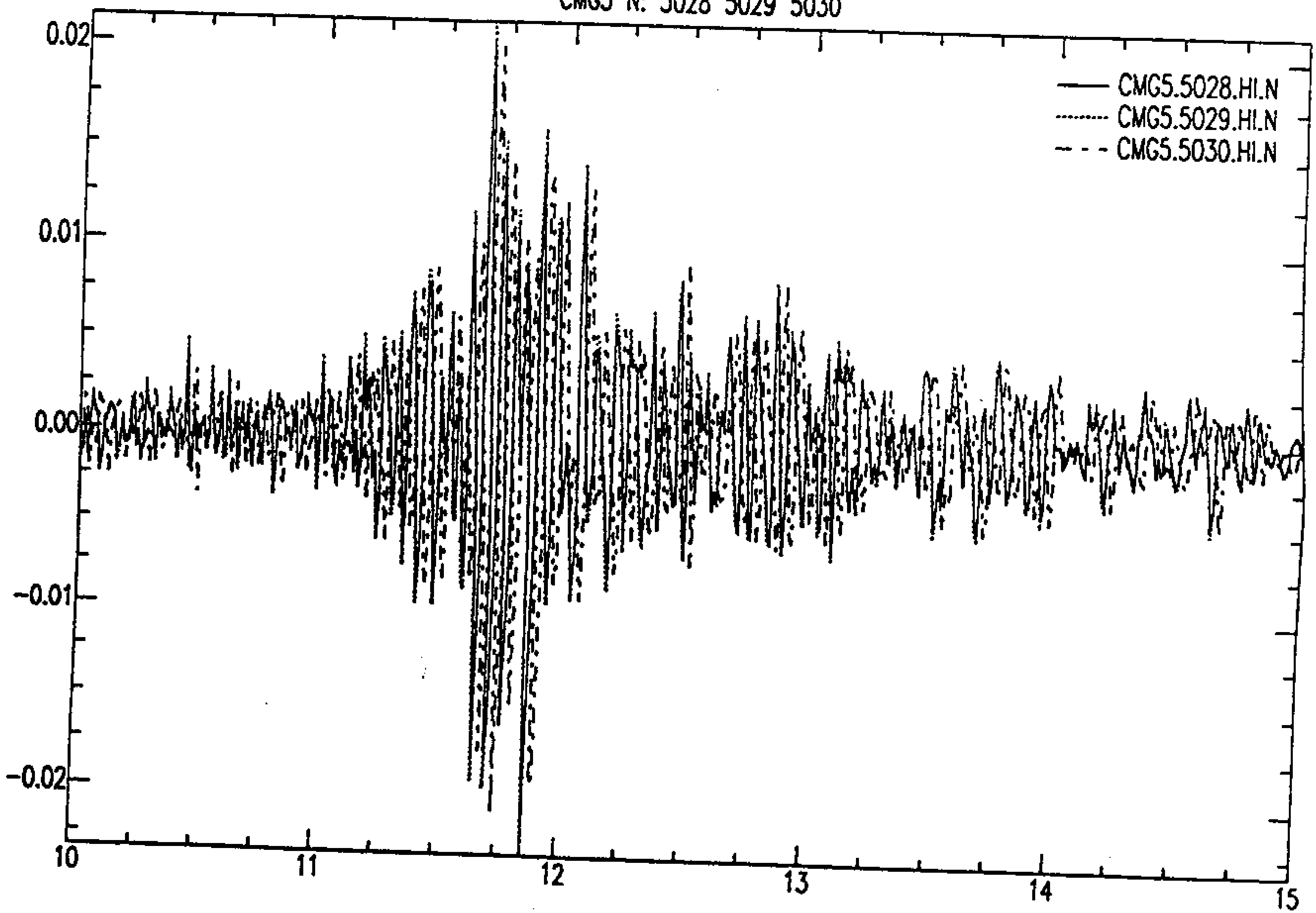
CMG5 low gain North component seismograms overlain.


CMG5 LO N: 5028 5029 5030 5035
CMG5.5028.LO.N
CMG5.5029.LO.N
CMG5.5030.LO.N
CMG5.5035.LO.N
X 10-3
2
1
0
-1
-2
8
9
10
11
12
13

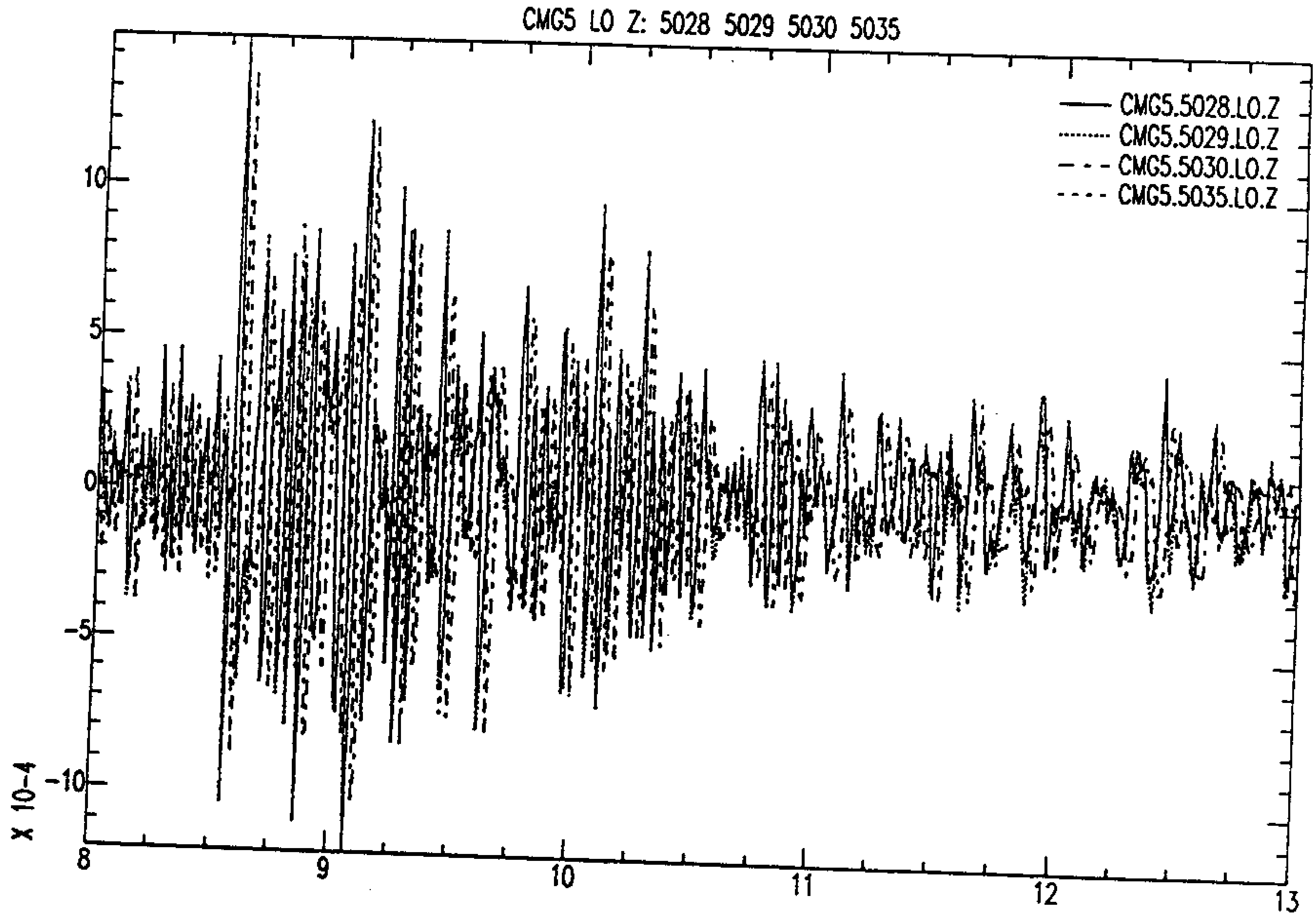
CMG5 high gain North component seismograms overlain.

H'

CMG5 N: 5028 5029 5030

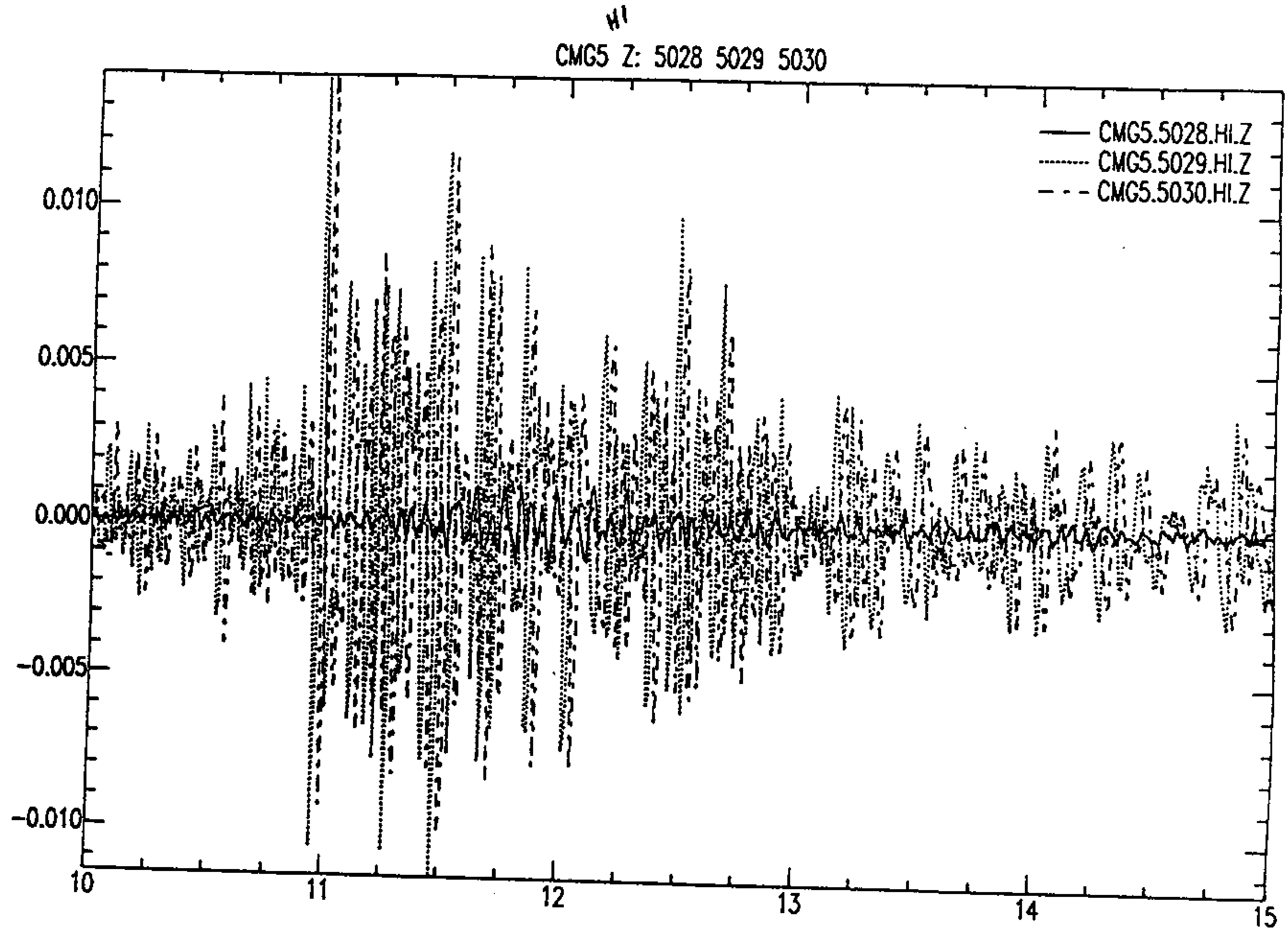


CMG5 low gain Vertical component seismograms overlain.

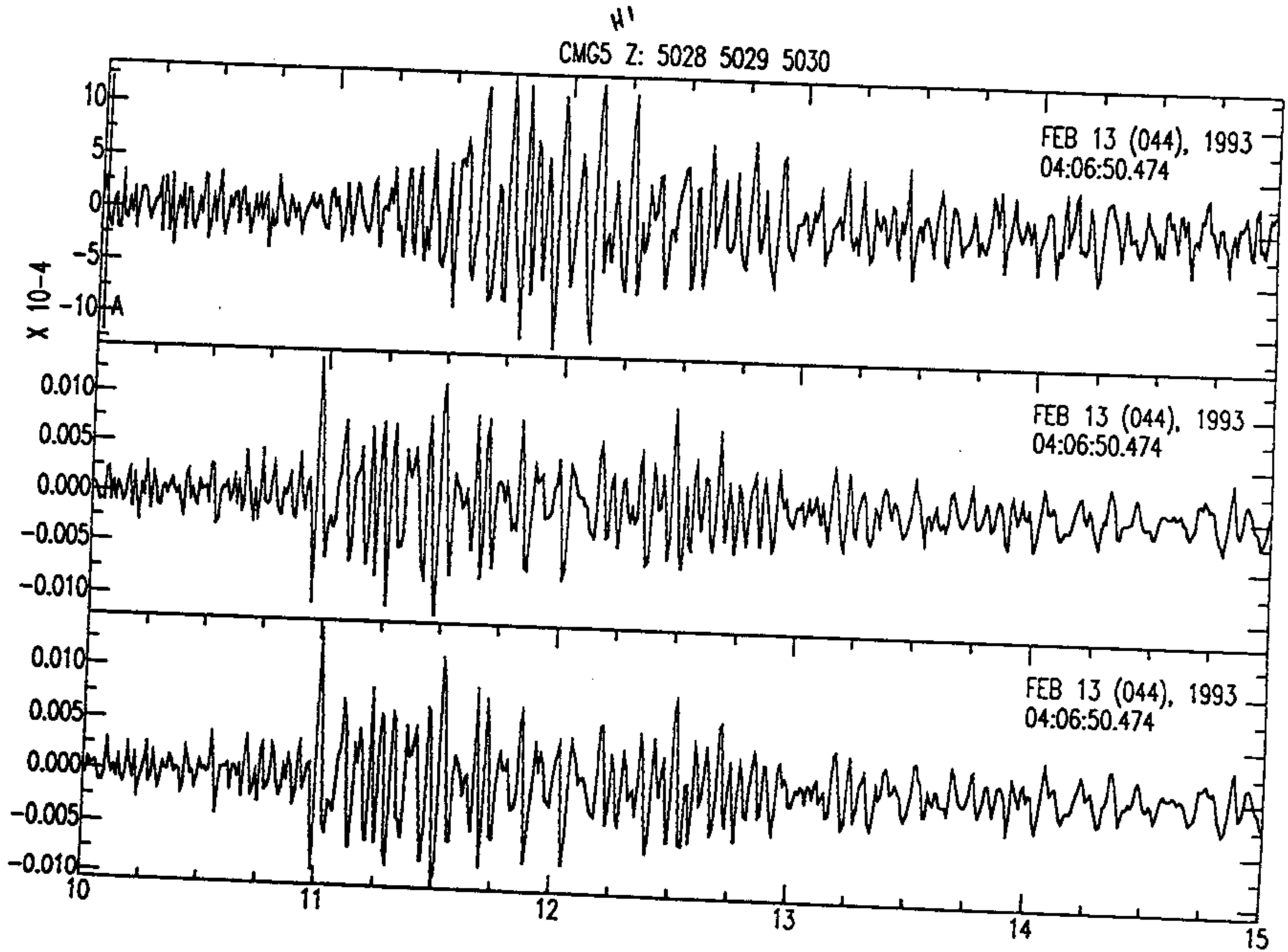


CMG5 LO Z: 5028 5029 5030 5035
CMG5.5028.LO.Z
CMG5.5029.LO.Z
CMG5.5030.LO.Z
CMG5.5035.LO.Z
X 10-4
10
5
0
-5
-10
8
9
10
11
12
13

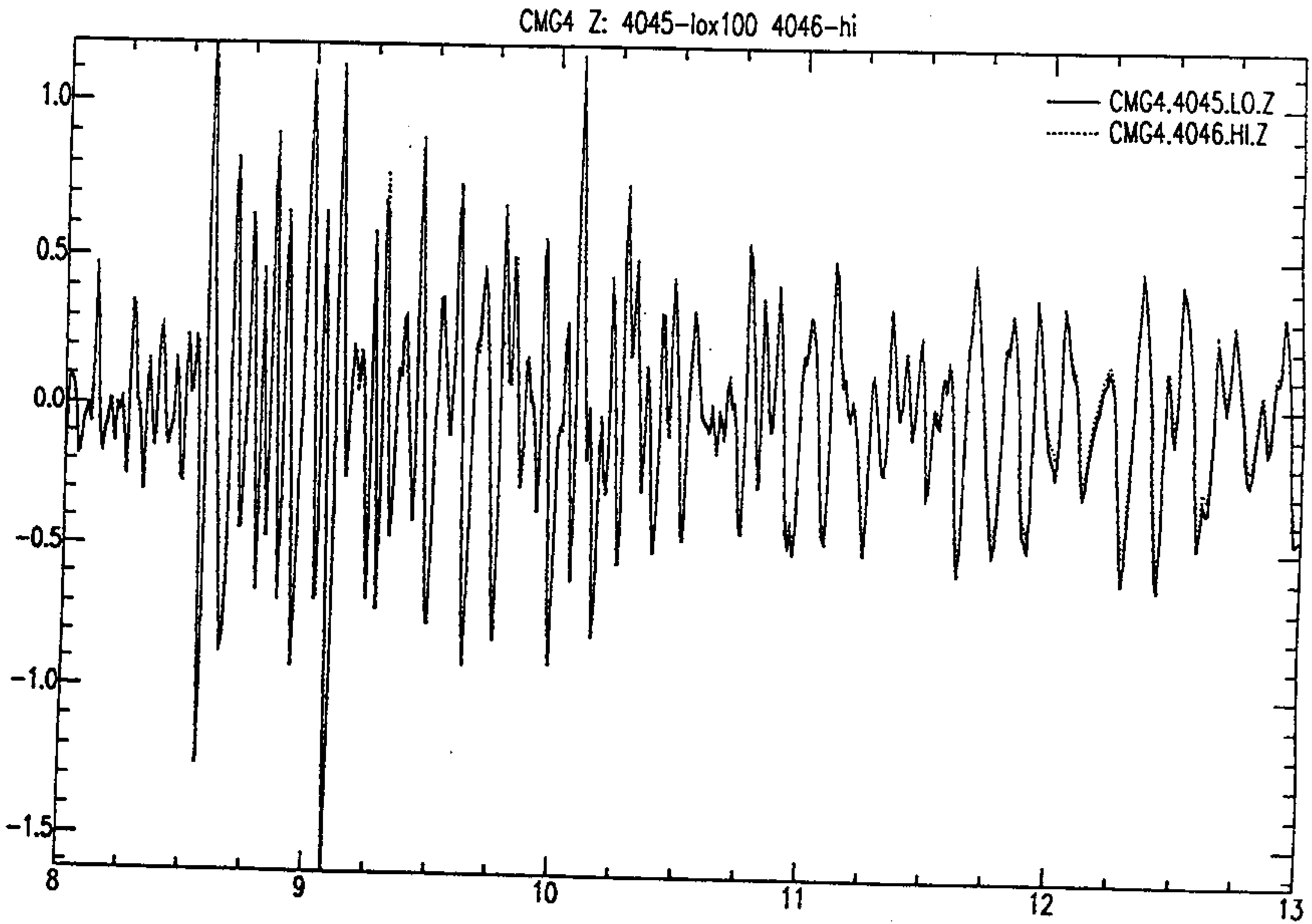
CMG5 high gain Vertical component seismograms overlain. Note reduced amplitude and phase character of seismometer #5028. The waveform character problem existed in the Little Skull Mountain aftershock deployment and is not understood (the low gain vertical of CMG5 #5028 is fine). The high gain vertical component of CMG5 #5028 should not be used because of this problem.


HI
CMG5 Z: 5028 5029 5030
CMG5.5028.HI.Z
CMG5.5029.HI.Z
CMG5.5030.HI.Z
0.010
0.005
0.000
-0.005
-0.010
10
11
12
13
14
15

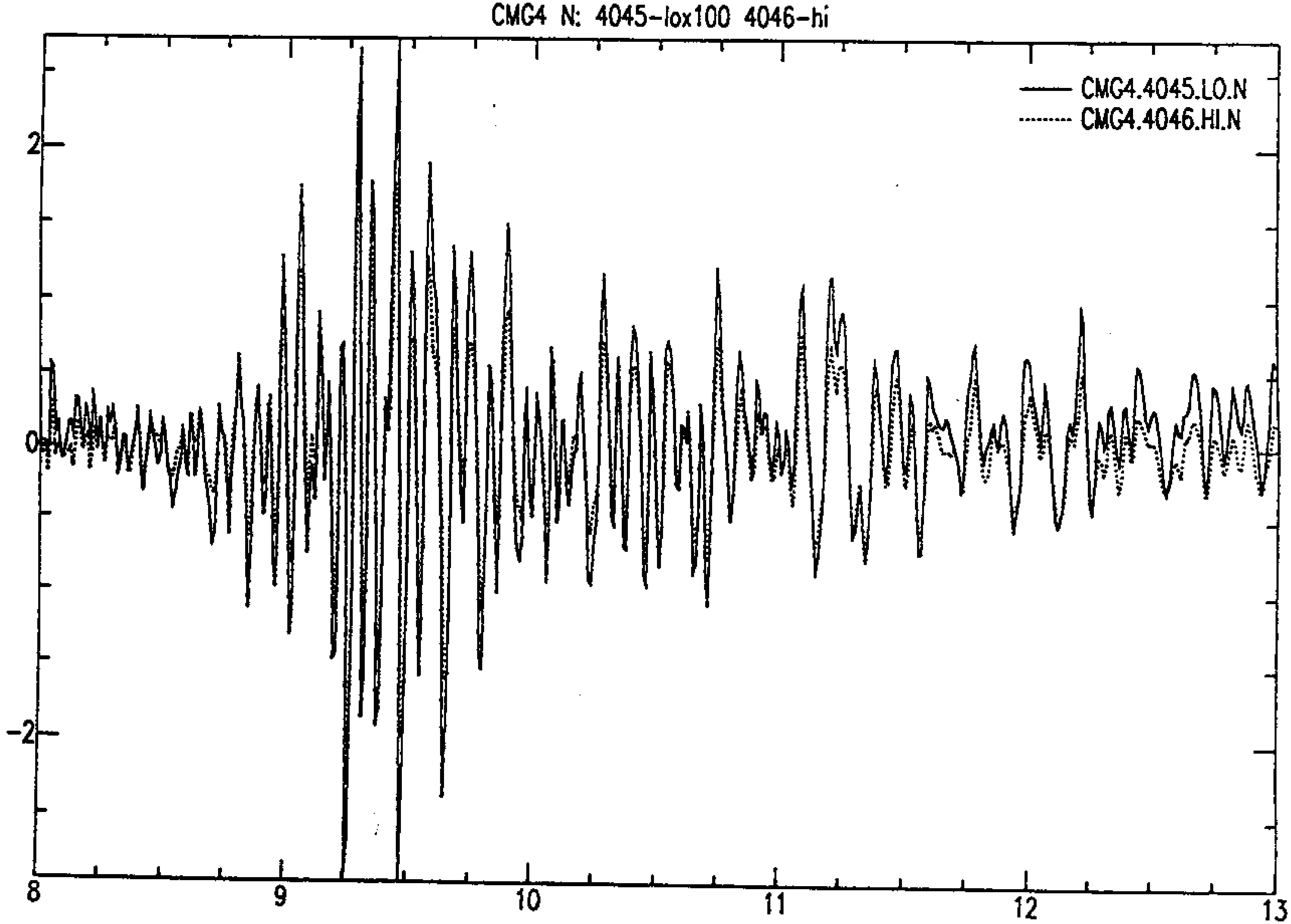
CMG5 high gain vertical component seismograms plotted one per plot to emphasize the different waveform character of CMG5 #5028


H'
CMG5 Z: 5028 5029 5030
FEB 13 (044), 1993
04:06:50.474
FEB 13 (044), 1993
04:06:50.474
FEB 13 (044), 1993
04:06:50.474
10
5
0
-5
-10
A
X 10-4
0.010
0.005
0.000
-0.005
-0.010
0.010
0.005
0.000
-0.005
-0.010
10
11
12
13
14
15

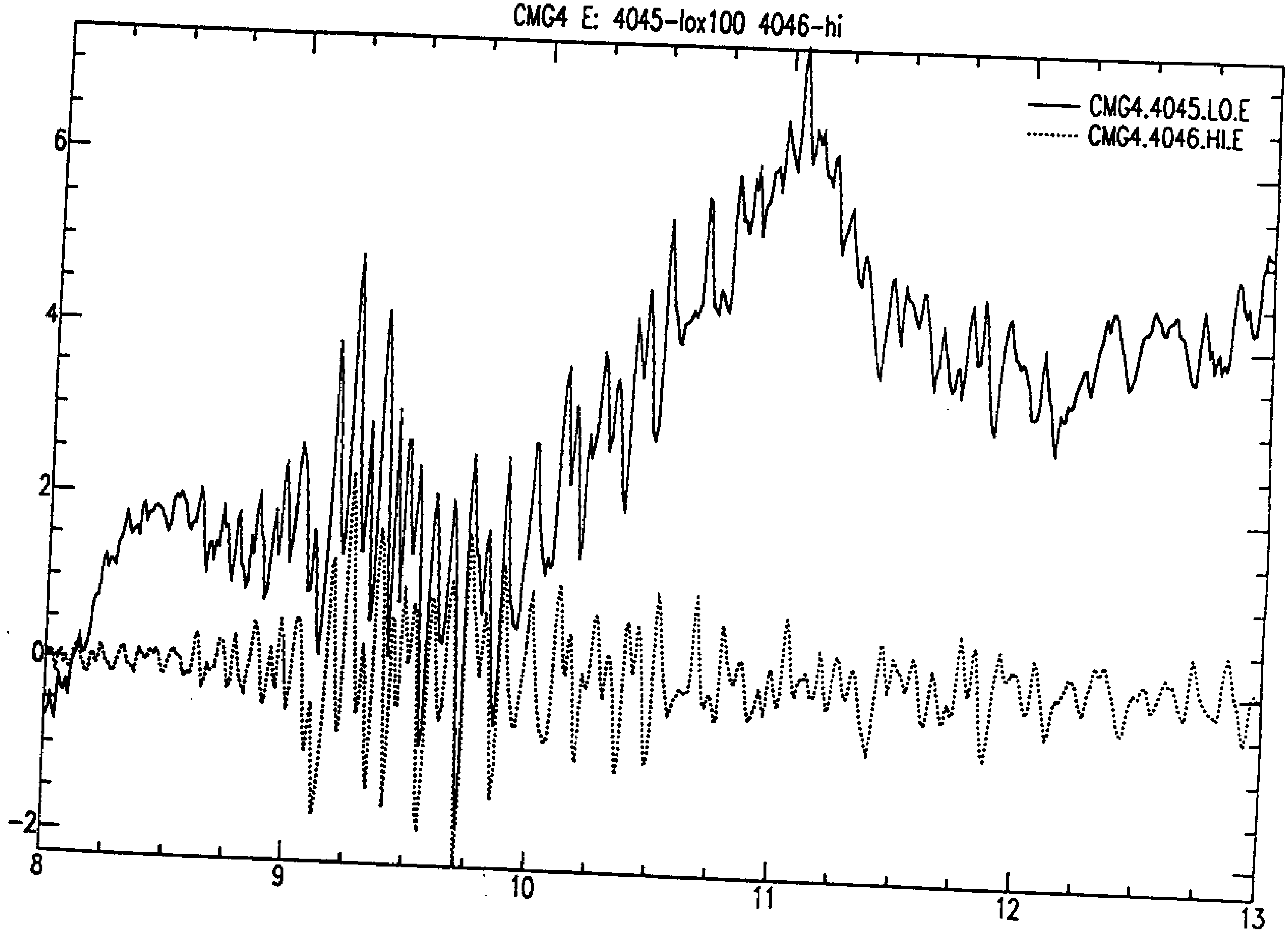
CMG4 vertical seismograms. Solid line is low gain of CMG4 #4045 multiplied by 100 (the difference in sensitivity between the low and high gain channels for the CMG4's) and the dashed line is the high gain vertical of CMG4 #4046. During the cluster test only the low gain of CMG4 #4045 and the high gain of CMG4 #4046 were recorded.


CMG4 Z: 4045-lox100 4046-hi
CMG4.4045.LO.Z
CMG4.4046.HI.Z
1.0
0.5
0.0
-0.5
-1.0
-1.5
8
9
10
11
12
13

CMG4 north-south component seismograms. Solid line is low gain of CMG4 #4045 multiplied by 100 (the difference in sensitivity between the low and high gain channels for the CMG4's) and the dashed line is the high gain vertical of CMG4 #4046.

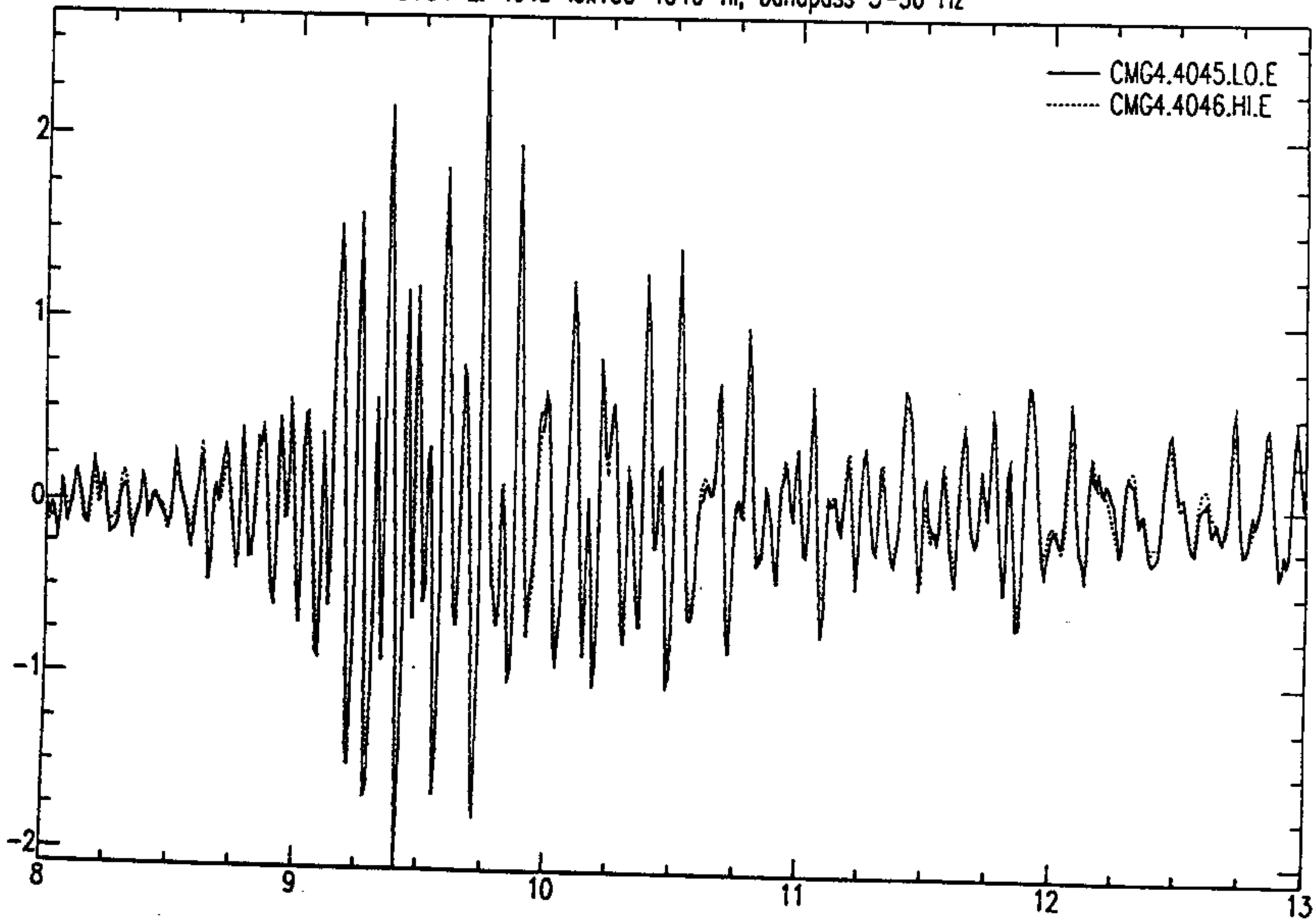

CMG4 N: 4045-lox100 4046-hi
CMG4.4045.LO.N
CMG4.4046.HI.N
2
0
-2
8
9
10
11
12
13

CMG4 east-west component seismograms. Solid line is low gain of CMG4 #4045 multiplied by 100 (the difference in sensitivity between the low and high gain channels for the CMG4's) and the dashed line is the high gain vertical of CMG4 #4046. Note the long wavelength noise on CMG4 #4045.


CMG4 E: 4045-lox100 4046-hi
CMG4.4045.LO.E
CMG4.4046.HI.E
6
4
2
0
-2
8
9
10
11
12
13

Bandpass filtered CMG4 east-west component seismograms. Solid line is low gain of CMG4 #4045 multiplied by 100 (the difference in sensitivity between the low and high gain channels for the CMG4's) and the dashed line is the high gain vertical of CMG4 #4046. A bandpass filter from 5 to 30 Hz reduces the long wavelength noise on CMG4 #4045.

CMG4 E: 4045-lox100 4046-hi, bandpass 5-30 Hz



III-D. Instrument Response Parameters

Factory values supplied Feb 1994

CMG5
high gain sensitivity = 5.22 $V/m/s^2$
low gain sensitivity = 0.522 $V/m/s^2$
3 poles:
-596.9026 0.0 Hz
-386.41589 634.60172 Hz
-386.41589 -634.60172 Hz
0 zeros
normalization constant (includes sensitivity):
high gain 8.5673×10^8
low gain 0.85673×10^8

CMG4 with 10 second corner (this is the variety used in the LSM experiment)
high gain sensitivity = 54600 V/m/s
low gain sensitivity = 546 V/m/s
2 poles:
-0.439823 0.448709 Hz
-0.439823 -0.448709 Hz
2 zeros:
0.0 0.0 Hz
0.0 0.0 Hz

CMG4 with 30 second corner (most of the posthole CMG4's are of this type)
high gain sensitivity = 14762 V/m/s
low gain sensitivity = 147.62 V/m/s
2 poles:
-0.148093 0.148096 Hz
-0.148093 -0.148096 Hz
2 zeros:
0.0 0.0 Hz
0.0 0.0 Hz

L22
sensitivity = 88 V/m/s
2 poles:

Real	Imaginary
-8.8857	8.8857 Hz
-8.8857	-8.8857 Hz

2 zeros:
0.0 0.0 Hz
0.0 0.0 Hz

IV. Timing Control for Reftek Instruments

IV-A. Omega Clocks

The Reftek Digital Acquisition System (DAS) configuration used in the Little Skull Mountain deployment uses the "OM-PCB Receiver to receive OMEGA transmissions and compute and continuously update the unit's knowledge of UTC time". (Quoted comments are taken directly from the Reftek 72A-02 Systems Manual, 1991 Refraction Technology, Inc., Omega Clock Manual; Refraction Technology, Inc. 2626 Lombardy Lane, Suite #105, Dallas, TX 75220, [214-353-0609]). "The accuracy of TIME from the OM-PCB is dependent on three external features. They are the signal strength, signal-to-noise ratio and propagation delay."

The OM-PCB is designed on a printed circuit board that is mounted in the chassis of the DAS. An external link for the OM-PCB to an antenna cable is provided by a BNC connector mounted on the facing of the DAS unit. An eight-foot antenna with the OMEGA preamplifier attached is bolted to a stake or post that is driven in the ground. To increase signal strength the antenna should be mounted on a topographic high whenever possible and the antenna/preamp setup should be grounded at the base to improve the signal-to-noise ratio. Local noise sources in the 11 to 14 kHz band (bandwidth of the OMEGA transmission) should be turned off or avoided. The propagation delay time from the transmitter to the receiver can be eliminated by "entering an accurate receiver position". "An error in receiver position of 186 miles [300 km] will cause a time error of 1 millisecond and an error in receiver position of 100 km or 62 miles will cause an error of 0.33 milliseconds."

"OMEGA is a very-low-frequency (VLF) hyperbolic radio navigation system, operating on a time-shared basis, with a total of eight stations transmitting phase and time synchronized signals. The VLF band from 10 to 14 kHz has been internationally allocated for OMEGA transmissions. The OMEGA system is designed primarily to provide position-fixing accuracy of 4 nautical miles 95% of the time. By the OM-PCB having knowledge of the transmission formats of each of the eight stations, knowing the receiver's approximate positions and the time to +/- 5 seconds, very accurate time can also be extracted from the system. The OMEGA navigation system was developed by the United States and is being operated in partnership with other nations. The eight permanent OMEGA transmitting stations are located in: Norway, Liberia, Hawaii, North Dakota, La Reunion Island, Argentina, Australia and Japan."

The following is a list of specifications of the Omega Clock Receiver configuration used in the Little Skull Mountain. deployment. These specifications are taken from the Reftek Omega Clock Manual.

Model OM-PCB-254 Specifications - OMEGA CLOCK

Antenna: Model A-12 antenna is supplied with the system. 8 ft. whip with universal mount, high impedance.

Preamplifier: Model PA-12 preamplifier is supplied with the system. Mounts to the base of the antenna bracket. High impedance input, 50 ohms output. Allows the use of 1000 ft of lead-in cable. The output connector is type "N" (bnc). Gain is 20 dB minimum. Bandwidth is 11 to 14 KHz.

Receiver
Input: Maximum 3 dB bandwidth 11.5 to 13.5 KHz. Maximum 20 dB bandwidth 10.4 to 14.6 KHz.Microprocessor tuned to the OMEGA station frequencies from 11.8 to 13.1 kHz.

Receiver
Sensitivity: Required signal strength at the antenna is 50 microvolts per meter.

Acquisition
Time: Typically 10 minutes from power on with average signal conditions.
Minimum - 5 minutes
Maximum - 20 minutes

Timing
Accuracy
UTC-UNSO: +/- 1 millisecond when locked to OMEGA Station. Operator must enter position to +/- .5 degree accuracy and time to +/- 5 seconds to UTC time.

Time Base
Stability: When tracking an OMEGA station, (locked):
Short term worst case (0-200 seconds):
$\pm 1 \times 10^{-6}/10$ s
Long term worst case (1 day):
$\pm 1 \times 10^{-8}$/day
Stability when not tracking an OMEGA station:
$\pm 5 \times 10^{-6}$ over -20° to +60°C.

Input/Outputs: All connections to the circuit board are made through two 64 pin DIN connectors. The user will supply the mating connector and make all connections to the antenna, power supply and other circuit boards.

1 Hz: 100 milliseconds pulse drives 10 LS TTL loads. Rising edge indicates the beginning of the UTC second.

1 kHz: 100 Millisecond pulse drives 10 LS TTL loads. Rising edge with 1 microsecond of 1 Hz pulse.

Serial Data: This output is a standard ASCII bi-directional interface. Default is time-of-year output in SOH D D D H H M M S S, an indicator of time quality, and CR/LF. Baud rate is jumper selectable. This output uses +5 volts for a mark and 0 volts for a space.

DC Power: +10.0 to 14 VDC. 20 mA nominal at +12V (with no loading).

Power Switch
Signal: TTL levels; high is power off and low is power on.

Mechanical Environment:

Size: Printed circuit board: 4.50" by 9.195: wide, not including connectors.

Weight: Receiver circuit board: .6 lbs. max (.275 kg). Antenna/Preamp/Lead in coax: 4 lbs max (1.8 kg).

Operating
Temp: Receiver: -20° to 60°C·
Preamplifier: -50° to +60°C.

Storage
Temp: -55° to +85°C·

Humidity: Receiver: 95%, non-condensing
Antenna/Preamp/Lead in coax: All weather.

IV-B. Little Skull Mountain Data Tapes and OMEGA Time Histories

Timing accuracy of the Omega Clock receiver is reported to the DAS during operation of the unit and is recorded in the LOG file which is written to the unit's disk drive. This file is recovered when the data is dumped to exabyte tape (in Reftek format) and subsequently converted to an ASCII file format on a Sun UNIX Machine with the PASSCAL program REF2SEGY. REF2SEGY also converts the raw trace data to SEGY format which is readable with other PASSCAL software. The following is a description of the timing information listed in the LOG file as reported by Jim Fowler of the PASSCAL Center at Lamont Doherty Geophysical Observatory. This description applies to the time history plots of the timing accuracy for each of the raw data tapes associated with the Little Skull Mountain Reftek deployment which follow.

From: jim@iris.edu (Jim Fowler) Subject: OMEGA problems
To: PASSCAL Users From: Jim Fowler November 21, 1991

The personnel at the PASSCAL Instrument Center have identified a problem with false locks being reported by the Kinemetrics Omega Clock. Initially it was thought that this problem could only occur under a very specific set of circumstances which did not happen in realistic field programs. However, after looking at a lot of data from various experiments we saw that is can happen fairly often if the clock stays unlocked for several hours.

We will have a program available to anyone who wants it on December 15, 1991. This program will look through log files and tell if there are any false locks. TrueTime has a new set of firmware which as near as we have been able to tell corrects the problem. You should contact Reftek or me to see about getting new EPROM'S for your clocks.

Please read the enclosed notice from the PASSCAL Instrument Center. If you have any questions or desire a copy of the program, just get in touch with me.

NOTICE FROM PASSCAL Instrument Center Lamont rwb

We have discovered that the Omega boards used in the Reftek 72A-02 DAS occasionally report a "false Omega lock": that is, they report CLOCK IS LOCKED when they are not actually locked to Omega. As with any lock, the DAS will set its internal clock to the time reported by the Omega board and data will be time shifted accordingly. Included here is a description of the problem, a method to identify whether this problem affects your dataset, and how to correct the problem. All PASSCAL Omega boards leaving the PIC since October 1, 1991 have been modified to eliminate this situation. If you are unfamiliar with clock messages in the log files please read the accompanying, more general document.

The Omega board contains its own oscillator, which free-runs when not locked to Omega. The DAS has a much better oscillator to keep time and does not use the time reported by the Omega board except when the Omega board reports lock. When a "false lock" occurs, the DAS clock is synchronized to the time of the free-running Omega clock which is likely to have a much higher offset to UTC than the DAS clock. As with any lock, the synchronization is handled in two ways, for offsets smaller than -5 or +10 milliseconds the DAS clock smoothly adjusts to the Omega time, otherwise it JERKs to the Omega time and reports the size of the JERK in the log file. A "false lock" always unlocks again within a few minutes so the DAS clock does not track the free-running Omega clock. Fortunately, the "false lock" situation doesn't occur often. It requires that a locked Omega receiver lose lock for a period of about 10000 seconds, or 2 hours 46 minutes, and even then does not occur in every instance. The "false lock" is a transient state caused by a bug in a loop counter of the Omega board software and is not related to the Omega broadcast signal. The effect of a "false lock" can be removed entirely if you pay careful attention to the log file.

"False locks" can be uniquely distinguished from real locks by the absence of a STATION IS indicator following the CLOCK IS LOCKED and CLOCK PHASE ERROR messages in the log file. Ignore CLOCK IS LOCKED messages which aren't followed by CLOCK PHASE ERROR, such as occur at start or stop acquisition: they are accurate and are not followed by STATION IS in any case. The "false lock"s usually occur 10000 seconds apart and may occur as many as 4 times, after which they cease until the next time the Omega board is locked and then unlocked for about 10000 seconds.

We have a short program to test log files for "false lock". It tests for the occurrence and sequence of character strings in the log file and reports all clock locks, flagging those which are false. To correct data files which have suffered a "false lock", subtract the corresponding "JERK" from the time of first sample for all files beginning after the "false lock" and before the next real lock. It may be necessary to sum the JERKs for a series of "false locks" before a real lock is encountered. For SEGY files it is sufficient to modify the header using PASSCAL programs segyshift or segymodhead. This is different from time corrections applied to data as a result of JERKs from real Omega locks in that one does not calculate the time correction for each file based on the DAS clock drift between UNLOCK and LOCK, but instead applies the whole JERK to every file. "False locks" which do not produce JERKs are more difficult to correct but also rarely require it.

ANSWERS TO SOME COMMON QUESTIONS ABOUT REFTEK TIME CORRECTIONS

What are EXTERNAL CLOCK IS LOCKED and EXTERNAL CLOCK IS UNLOCKED messages?

LOCKED means the external clock is synchronized to an Omega transmitter. When this happens, the Reftek in turn is synchronized to the external clock. The log file should indicate which Omega station is being received, for example, STATION IS HAWAII. (It does not matter which Omega station is being received, because the clock calculates the delay for the path between each station and the Reftek.)

If the clock was UNLOCKED for a significant period of time, it may be worth attempting manual time corrections. How long is significant? We test each Reftek recorder to verify that it meets the manufacturer's specification of plus/minus .5 ppm time base stability. That means that the worst-case drift of an unlocked clock is plus or minus 40 milliseconds per day. So whether a correction is necessary depends on the time resolution you are looking for and the length of time the clock was unlocked. (There is another factor: whether or not events exist during the period the clock was unlocked!) Finally, look for TIME JERK messages (see below). Frequently, if there are no time jerks, no time corrections will be necessary.

What about EXTERNAL CLOCK ERROR messages?

They should be ignored. They represent a worst-case estimate of the error that may have accumulated in the external clock itself, when that clock is not locked to an Omega transmitter. The Reftek does not use the external clock except when locked, thus the messages are meaningless. The only information they communicate is (roughly) time since last lock, because the EXTERNAL CLOCK ERROR passes through four stages: 1, 5, 50, and 500 milliseconds. These are the same numbers that appear on the Epson Hand Terminal status display.

What about CLOCK PHASE ERROR messages?

These are the significant ones. The sign follows the usual convention: clock time + error = true time. Messages with very small errors (USECONDS, or microseconds) are normally written to the log file when a station is locked. They verify that the external and internal clocks agree, at least at the time of the message!

Messages with large errors (MSECONDS, or milliseconds) are written when a clock which has been unlocked for some time relocks. They may be associated with a TIME JERK message.

What is a TIME JERK?

A TIME JERK is a step reset of the internal clock. This will occur if the phase error between the external and internal clocks exceeds the limits of -5 and +10 milliseconds. Normally this only happens if the external clock has been unlocked for a long time (several hours) and then relocks. The time of the jerk will be logged, and there will be a CLOCK PHASE ERROR message generated before and after the jerk. Errors less than the above limits are corrected by gradually adjusting the clock ("slewing") at a rate less than 6 ppm.

What is the DSP clock?

The DSP is the "digital signal processing" chip. The Reftek data are time tagged in the digital signal processor, at the same time that the steps of digital filtering and decimation are carried out. The DSP clock will be reset every time that a time jerk occurs. The old and new times are written to the log file. However, due to the software implementation of the internal clock, there will be instances where this reset occurs in two separate steps (e.g., seconds and milliseconds).

How do I time-correct the data?

There are two programs in the standard PASSCAL distribution that are capable of correcting the start time of a SEGY trace: segyshift and segymodhead. Refer to the appropriate manual pages for these programs. Note that in both cases the programs modify the trace headers, not the actual data.