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1990 PINYON FLAT HIGH FREQUENCY ARRAY EXPERIMENT
AN IRIS EURASIAN SEISMIC STUDIES PROGRAM
PASSIVE SOURCE EXPERIMENT

Submitted By

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and Daniel E McNamara

for the
Project Science Team

PASSCAL Data Report 91-002

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Data Report

for

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ABSTRACT

This report describes the data from the 1990 Eurasian Seismic Studies Program Pinyon Flat High Frequency Array Experiment. The array consisted of a grid of 58, 3-component, short period seismometers and 30 PASSCAL recorders triggered by two, 3-component, borehole sensors. A total of 325 seismic events (including about 150 with known locations) were recorded. Data formats, auxiliary information, calibration information, and organization of the distribution data tapes are discussed.

1. Introduction

The Pinyon Flat Passive Source High Frequency Array Experiment of the IRIS Eurasian Seismic Studies Program was conducted in April and May, 1990, at Pinyon Flat Observatory, California (Figure 1). Goals of the field portion of the experiment were to obtain a detailed, unaliased record of the seismic wavefields from local and regional events, as well as to test and prepare equipment and personnel for similar ESSP deployments in the Soviet Union during 1991 and 1992.

Pinyon Flat Observatory (PFO) was chosen as the experiment site for its high levels of local seismic activity, the potential for recording regional earthquakes from California and Baja, and its proximity to the Nevada Test Site. Existing seismic coverage at PFO and the surrounding area provided guidance concerning event location as well as expected site response. A total of 325 events were recorded between April 18, 1990, and May 27, 1990.

The array operated in master/slave mode, with elements of the array triggered by two borehole sensors located at depths of approximately 150 and 275 meters. The borehole instruments are part of a permanent USGS installation at PFO and have been in operation for several years. Use of the borehole sensors as masters in trigger decisions significantly reduced false triggers. Over the duration of the experiment, approximately 87% of the slaves triggered in response to a master trigger command. A large percentage of the "failure to trigger" data loss was due to problems with the central power distribution system early in the project. Very few data were lost due to instrument failure.

The array contained 58, 3-component, L-22 (2 Hz) sensors and 29 PASSCAL data recorders, each recording on 6 channels. Signals from the two borehole receivers were recorded using one additional PASSCAL recorder, bringing the total number of seismometers to 60 and the total number of PASSCAL recorders to 30. The externally triggered data streams were recorded at a sample rate of 250 samples/sec. The triggers were STA (short-term average) to LTA (long-term average) ratios. The STA and LTA windows were 0.1 and 30 seconds respectively, and the STA/LTA trigger threshold was set at 10. The data streams used pre-event buffers of 15 seconds and an overall record length of 90 seconds. Data recording was done in 16 bit mode, so an event triggering all receivers generated just over 8 Mb of data.

The array was configured as a grid with two orthogonal arms (Figure 1). Sensor spacings of 7 meters within the grid and 21 meters on the arms were chosen to aid analysis of body to surface wave conversions at high wavenumbers. All elements of the array were linked to a common time signal from a single OMEGA time clock to ensure precise timing over short distances. The sensors were oriented, leveled, and set in a plaster pad at the bottom of pits dug 1 to 4 meters through an unconsolidated sandy surface layer and into the underlying weathered granitic material.

2. Project Science Team

The Science Team for this deployment consisted of the following individuals, all of whom contributed significantly to the data collection effort and thus to this Data Report:

Name	Institution
Paul Anderson	Indiana University
Jeff Babcock	University of California, San Diego
Dan McNamara	University of South Carolina
Tom Owens	University of South Carolina
Gary Pavlis	Indiana University
Frank Vernon	University of California, San Diego

In addition, significant technical and software assistance from the staffs of the Institute of Geophysics and Planetary Physics at UCSD (Scripps Institution of Oceanography) and the PASSCAL Instrument Center (Lamont-Doherty Geological Observatory) was essential. Specific individuals are mentioned in the Acknowledgements.

3. Description of Data Distribution

The High Frequency Array data has been provided to IRIS in five sequential subsets grouped by Julian Day plus one directory of auxilliary information. Each subset of data and the auxilliary directory are archived on individual exabyte tapes in UNIX tar format. The subsets and their sizes are described in the table below. The entire data distribution totals just under 2 gigabytes in size.

Data Subset	Julian Days	Size (Mb)	Number of Events
I	108-111	154	18
	114-118	361	57
II	119-125	424	64
III	126-131	467	70
IV	132-139	536	71
V	140-148	321	45

All trace files in this distribution are written with trace header structure defined by the SEG-Y standard (Barry et al., 1980). The trace headers contain some additional fields set by the IRIS supplied *ref2segy* processing software. The trace data in each of the subsets are distributed using the following directory structure and file naming convention:

events/90JDAY/90JDAY.HH.MM.SS/TRACEFILE

where *JDAY* is the 3-digit number of the Julian Day and *HH.MM.SS* is the event time in hours, minutes, and seconds. *TRACEFILE* is of the form:

*x##y##.** for surface sensors

or

*mbeast.** or *mbwest.** for the east and west master/borehole sensors

where * represents letter e, n, or z corresponding to the east/west, north/south, or vertical alignment of the sensor axis and *x##y##* indicates an index position of each sensor in a Cartesian coordinate system with +x in the east direction and +y to the south. All sensor positions are numbered relative to *x*00*y*00 at the northwest corner of the grid. For example, *x*05*y*05 is at the southeastern corner of the grid, *x*03*y*16 is at the southern end of the north/south arm, and *x*16*y*03 is at the east end of the east/west arm.

3.1. Auxilliary Information

This data distribution is accompanied by a directory of auxilliary information (*ESSP_PFO_90*) that may be needed by individuals using these data. The subdirectories include:

ESSP_PFO_90 *|Data_Report*
|Event_Info
|Hit_Plots
|Pinyon_db
|SOH_Files
|Software
|Tape_Lists.

In the following paragraphs, we describe the contents and formats of the files contained in these directories.

3.1.1. */Event_Info*

About 150 events were located by either the Anza or the Caltech seismic networks. A table correlating our event directories with the event location information obtain from these networks is given in the file *Located_Events* in the *./Event_Info* subdirectory. A sample entry is:

115.16.26.39:115.16.26.51.0000:33.5117:-116.4523:.0:8.3:11.00:0.10

The fields are colon (:) separated. Field 1 is the event directory from our data distribution tapes. Other fields are described in the file *README* located in this subdirectory.

3.1.2. */Hit_Plots*

To aid in locating well recorded events, we constructed "Hit Plots" of the form shown in Figure 2 using SAC. These plots are included in the data distribution in the */Hit_Plots* subdirectory. All the plots are provided in SAC SGF format. File names of the form *hits*001*.sgf* are SAC SGF files. The file *SGF_Plots* correlates event directories with SGF filenames. In addition, the file *Hit_List* gives the number of grid sites triggered for each event directory. The maximum possible triggers is 58.

SAC stands for the Seismic Analysis Code developed at Lawrence Livermore National Laboratory. SAC and utilities for translating SGF files into PostScript are distributed by LLNL and by the IRIS Data Management Center.

3.1.3. */Data_Report*

We have included in subdirectory *./Data_Report* a complete version of this report in UNIX troff format. Figures are in separate files in PostScript format. On our Sun Microsystems workstations, the data report may be printed using:

tbl *essp_pfo_90.txt* | eqn | ptroff -t -ms

The figures may be printed on a PostScript printer using:

lpr *fig*.ps*

3.1.4. */Pinyon_db*

Files contained in *./Pinyon_db* conform to the naming convention:

./Pinyon_db/JDAY.HH.MM.db

where the file name *JDAY.HH.MM.db* corresponds to the date and time the file information becomes "active". The original database file was updated whenever changes affecting file content were made to the array. Hence the sequential file names. The files contain L-22 and Reftek DAS (Data Acquisition System) serial numbers for each site in the grid, along with relative site positions and channel polarity information. The file formats are described and examples given in file *PFO_90_Database*.

3.1.5. */SOH_Files*

The contents of the State of Health subdirectory (*./SOH_Files*) are of the following form:

./SOH_Files/90JDAY/90JDAY.I####.err

or

./SOH_Files/90JDAY/90JDAY.I####.log

where #### is the Reftek DAS serial number. The *ref2segy* State of Health file is contained in **.log*, and the *ref2segy* error file is contained in **.err*. *Ref2segy* is provided by the PASSCAL Instrument Center as part of the standard field computer software.

In addition, the file *Clock_Info* in this directory contains a compilation of the SOH entries pertaining to clock performance. Since the timing of all instruments was derived from a single clock, this information can be considered applicable to all sites. Clock performance in general was excellent, with only minor dropouts. Also in this directory is the file *Bad_Blocks*. This file contains entries from the SOH files related to unidentified blocks extracted from the DAS units. These blocks are dropped by *ref2segy* and thus the traces involved could have corrupted traces. Each of these entries is related to a specific trace in the data set. The entries reference a trigger time, component, and DAS serial number. Users will have to use the database files in */Pinyon_db* to correlate these with a specific file in our data distribution. There are 71 entries in this file. For reference, about 50,000 traces were recorded during this experiment, so the problem is very rare.

3.1.6. */Software*

The */Software* subdirectory contains 2 subdirectories, */calibrate* and */segy2sierra*. We are providing this software because we think most users of this data set would find the codes valuable. However, the software is provided "as is" with absolutely no guarantees. The software is not supported by the members of this project nor by IRIS. We have compiled and are using these codes on our Sun SPARCstations running SunOS4.1. Individuals who decide to use these codes are reminded that they are responsible for installing, testing, and debugging the codes for use in their own systems.

Subdirectory */calibrate* contains software to correct for differences in sensor characteristics. The procedure is outlined in some detail in Section 3.4 of this report. The L-22 calibration data is contained in *L22.table*. The calibration source code is contained in *equalize_segy.c* and a Bourne shell script for processing large numbers of events is contained in *equalize*. Further information along with instructions and commands for running and compiling the code are found in *README* and *makefile*.

Subdirectory */segy2sierra* contains a second, specialized piece of software that we hope can help others in working with these data. This code was derived from a program originally written by Richard Boaz of the PASSCAL Instrument Center, but was subsequently modified substantially by G. Pavlis. We are supplying this code primarily to help others avoid the rather unexciting, but necessary job this program does. However, we state for the record that this code comes with no support or implied guarantee of any kind.

Functionally, *segy2sierra* does only one major task; it assembles the pseudo-SEG-Y disk files organized in event directories (common shot gathers), and builds a true SEG-Y format tape. (One can optionally use the same program to build a *Sierraseis* SEGYDIN format disk file, but that mode is probably of less utility for most potential users of these data because of the size of the data set.) The resulting SEG-Y tape can then be processed with a reflection processing package like *Sierraseis*. The source code is contained in *segy2sierra.c*. Further documentation along with instructions for running and compiling the code can be found in *README* and *makefile*.

3.1.7. */Tape_Lists*

The subdirectory *./Tape_Lists* contains five files named:

tape#.con

where # indicates one of the five data subsets. Each file contains a list of the file names on the corresponding tape.

3.2. Data Preparation

Raw field traces were converted to SEG-Y format using program *ref2segy* provided by the PASSCAL Instrument Center. Data were associated by event times using a modified version of PASSCAL Instrument Center program *cluster*. In this process, the triggers on the borehole sensors were used as reference events and all array triggers at the same time were combined into the appropriate event directory using the naming convention described above.

Early in the experiment, we experienced throughput problems on the master DAS (the DAS recording the borehole sensors) during triggering. The result of this problem is that the DAS sometimes inserted duplicate blocks of data into the recorded data streams. This blocks are normally 1 second long and are very difficult to detect in local earthquakes unless they happen to occur between the P- and S-wave arrivals. This problem was fixed on Day 121. Thus, users are advised to scrutinize the traces from the borehole sensors for days 108 - 121 before analyzing these data.

Also, a second DAS bug resulted in occasional dropped blocks of data recorded in the output stream. This problems was always flagged by *ref2segy*. File *Bad_Blocks* in the auxilliary directory */SOH_Files* contains a list of triggers that have this problem. Users are advised to scrutinize these traces as well before using them in their research.

All traces were visually previewed in an attempt to identify dead channels, as well as polarity and gain problems. Dead channels were deleted. Polarity and gain problems were corrected. All traces were examined, but traces from events with high signal to noise ratios were inspected more closely than others, particularly with regard to polarity since reversed polarity can be very difficult to recognize in the presence of poor signal quality. Events with high signal quality were used as "marker" events of an interpolation process to identify and correct traces with polarity, gain, or dead channel problems. For example, if inspection of trace *x01y00.e* indicated reversed polarity in marker event *A* and again in marker event *B*, then *x01y00.e* polarity was corrected in marker events A and B as well as in all events between A and B. This approach is considered viable because problems with polarity, gain, and dead channels were generally tied to some "steady state" hardware problem existing over a significant period of time. However, an undesireable implication of this approach is that any transient or "isolated" problems confined between marker events may not have been recognized (or corrected) at all. For example, the DAS on sites x01y04 and x00y04 apparently reversed polarity on the north/south components prior to event 90.139.09.48.19 and again after event 90.139.11.36.56. We have not corrected for the problem in this case and have no explanation for the occurence. We have seen no similar problem to date, but users need be aware of this unexplained occurence.

Each tape in the data set (subsets I-V of the table) contains information regarding corrections made for polarity, gain, and dead channel problems. The information is in files with the following naming convention:

events/dead/90JDAY.dead

where 90*JDAY.dead* contains the trace file names for traces deleted from events recorded on Julian Day *JDAY*;

events/polarity/90JDAY.pol

where 90*JDAY.pol* contains the trace file names for those traces corrected for reversed polarity; and

events/gain/90JDAY.gain

where 90*JDAY.gain* contains trace file names for traces that required gain correction. (Note: The only traces requiring gain correction were *x*03*y*04.* between *JDAYS* 114 and 135. A gain change entered on *JDAY* 114 did not register correctly with 3 channels of a single PASSCAL box. The applied correction factor was 1/16.)

In spite of the dry climate at Pinyon, a number of stations in the array had serious problems with 60 Hz noise. The problem was produced by a combination of two elements of the array design: (1) the instruments were fed with AC power and (2) the master-slave and timing circuitry did not have optical isolation and consequently tied the grounds of all the boxes together. No attempt has been made to address the 60 Hz problem during preparation for this data distribution, so users will need to consider notch filtering for data quality improvement.

3.3. Located Events

As many events as possible have been correlated with locations obtained from the Anza and Caltech networks. We initially required that the origin time of the event be within 10 seconds of an event trigger time for a successful correlation. The window was then slowly expanded for events for which we had known locations but apparently did not trigger the master borehole sensors. A table of these locations is provided in the auxiliary information directory as described above. A sample event is plotted in Figure 3. Because we have not looked at every associated event, there is a possibility that we have associated an earthquake location with another, unrelated event. As always, users of this data should verify that the location and the event are compatible.

3.4. Calibration

None of the data we have prepared for distribution have been corrected for differences in sensor characteristics. However, all of the L-22 sensors we used had been previously tested and calibrated by the PASSCAL instrument center at Lamont. The procedure they used is described in a recent paper by Menke et al., 1991.

The calibration data that is available parameterizes each sensor using the standard equations for a mass-spring seismometer with a magnetic coil sensor. That is, beginning with the standard equation for the frequency response of a pendulum seismometer, describe the equation of motion for a damped harmonic oscillator:

$$S(\omega)=\frac{-\omega x^2}{(\omega^2-\omega_0^2)+2i\varepsilon\omega}$$

where $\omega_0=2\pi f_0$ with f_0 representing the natural period of the seismometer and ε is the damping factor. The tables produced by the instrument center actually use the parameter $\lambda=\frac{\varepsilon}{\omega_0}$. λ is the familiar damping parameter where $\lambda=1$ defines critical damping.

We modified a program written originally by Bill Menke to apply these calibration data to SEG-Y trace data from this experiment. The program uses a simple frequency domain calibration correction. That is, it can be shown that the transfer function to correct a given measured seismometer response to a standard L-22 sensor is given by

$$T(\omega)=\left[\frac{(\omega_0)_n^2(x_0)_n}{\omega_0^2 x_0}\right]^{1/2}\left[\frac{(\omega^2-\omega_0^2)+2i\lambda\omega\omega_0}{(\omega^2-(\omega_0)_n^2)+2i\lambda_n\omega(\omega_0)_n}\right]$$

where x_0 is the sensitivity constant as defined by Menke et al (1991). It is not an absolute calibration constant. The n subscript labels a parameter as being a fixed constant describing a nominal, standard 2-Hz, L-22 seismometer ($(x_0)_n=0.015$, $(f_0)_n=2$ Hz, and $(\lambda_0)_n=0.7$). In addition to doing calibration equalizations, the reader should note this program also has two side benefits: (1) it removes the mean from each trace, and (2) it sets the receiver coordinates to the proper value in the SEG-Y header of each trace it processes.

The table containing the calibration data produced by the Passcal Instrument Center (as described in Menke et al., 1991) is contained on a file named *./Software/calibrate/L22.table.* This file is a flat table file in the format used by the ***Geobase*** program that was recently developed at Lamont. This is an ASCII file organized as follows:

Line 1: Keyword symbols identifying the fields of data that follow. (This information is not used by the calibration program, but can help you identify fields.)

Line 2: A sequence of words describing the data format these data were originally stored in by *Geobase* (This line is ignored, but kept for compatability with *Geobase* .)

Line 3 ... Data records.

In every line, individual fields are separted by tabs. The first line of the file defines each field. Symbols used are as defined in Menke et al., 1991, but for completeness they are as follows:

l22 = serial number of sensor

comp = sensor component (1=Vertical, 2=N-S, and 3=E-W components)

gain = (not used)

x0 = x_0 = relative gain constant defined in Menke et al., 1991.

f0 = f_0 = free period of sensor

lambda = λ = damping parameter (see below).

In all cases the table contains two extra columns labeled + and -. These are results from calibrations made with opposite polarities (Menke et al., 1991). The columns without a + or - are the average of the + and - fields, and these are the ones we use.

To correct the data, we have to associate the proper calibration with each trace. The equalization program supplied with this data distribution does that by reading the database files in *./Pinyon_db* describing what sensor was at what station, by reading the L-22 calibration table in *./Software/calibrate* produced by the PASSCAL Instrument Center, and then associating the proper sensor parameters with the proper trace and performing the trace equalization calculations. Instructions for running the program are contained in */Software/calibrate/README* (see Section 3.1.6 of this report).

4. Acknowledgements

This project was funded by grants from the IRIS Eurasian Seismic Studies Program to the University of California-San Diego, University of South Carolina, and Indiana University. Technical assistance from Chris Winther Glen Offield and James Batti of UCSD was essential to this project. Software assistance from Richard Boaz of the PASSCAL Instrument Center was equally helpful. The SIOseis package and installation assistance from Paul Henkart allowed us to efficiently plot our raw data. Instrumentation for this experiment was provided by PASSCAL. The assistance of James Fowler, PASSCAL Chief Engineer is gratefully acknowledged. Sensor calibration by the staff of the PASSCAL Instrument Center resulted in the information included in Calb_Info/L22.table.

5. References

Barry, K.M., D.A. Cavers, and C.W. Kneale, Recommended Standards for digital tape formats, in *Digital Tape Standards*, pp. 22-30 Society of Exploration Geohpysicists, Tulsa, Ok., 1980.

Menke, W., L. Shengold, Guo Hongsheng, Hu Ge, and A. Lerner-Lam, Peformance of the short period geophones of the IRIS/PASSCAL array, *Bull. Seism. Soc. Am.*, 81, 232-242, 1991.

6. Data Distribution

The Data referenced in this report may be obtained through:

IRIS Data Management Center
8701 Mopac Blvd., Suite 205
Austin, TX 78759
Telephone: (512) 471-0403, 0404, or 0405

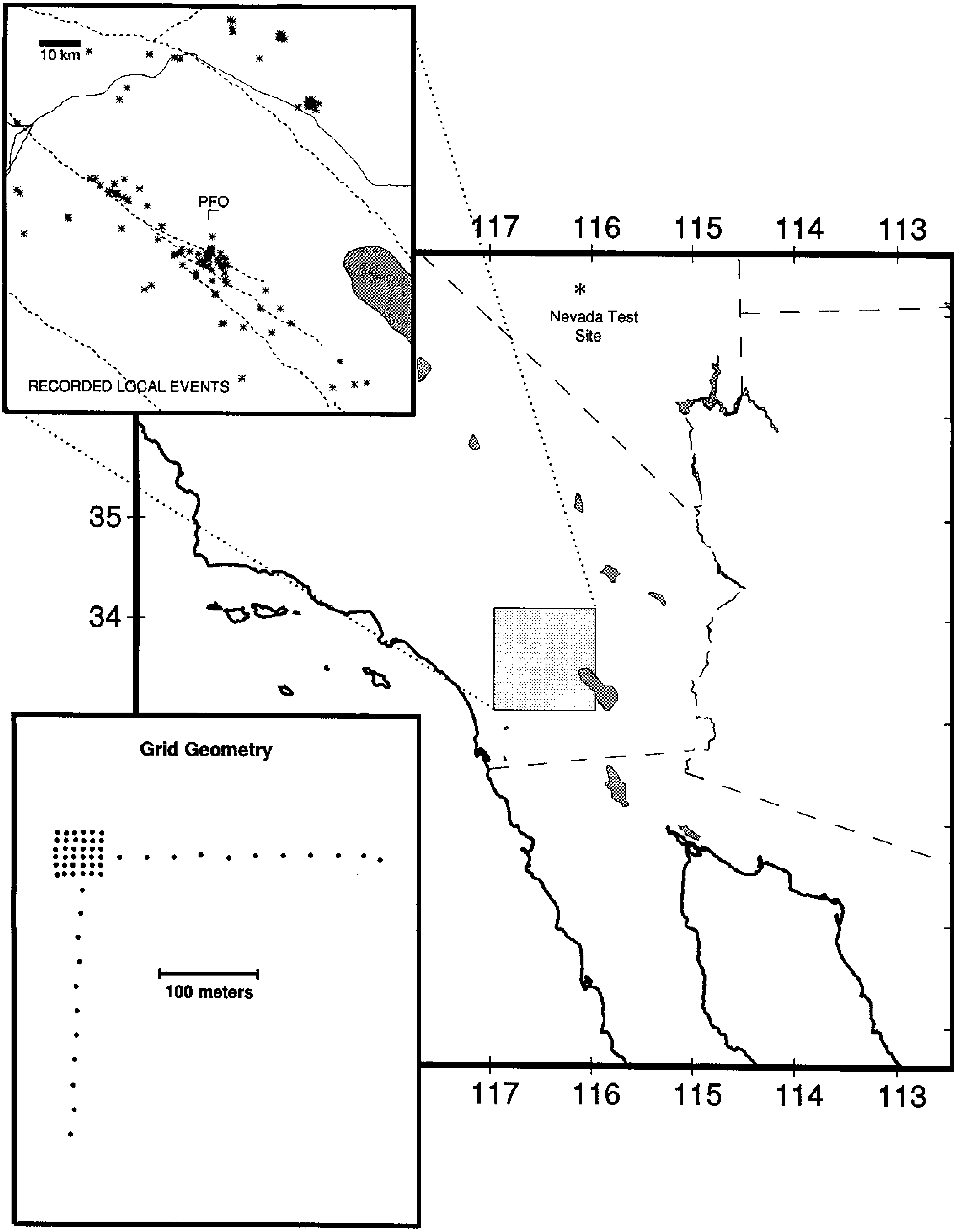

Figure 1: 1990 Pinyon Flat High Frequency Array Experiment

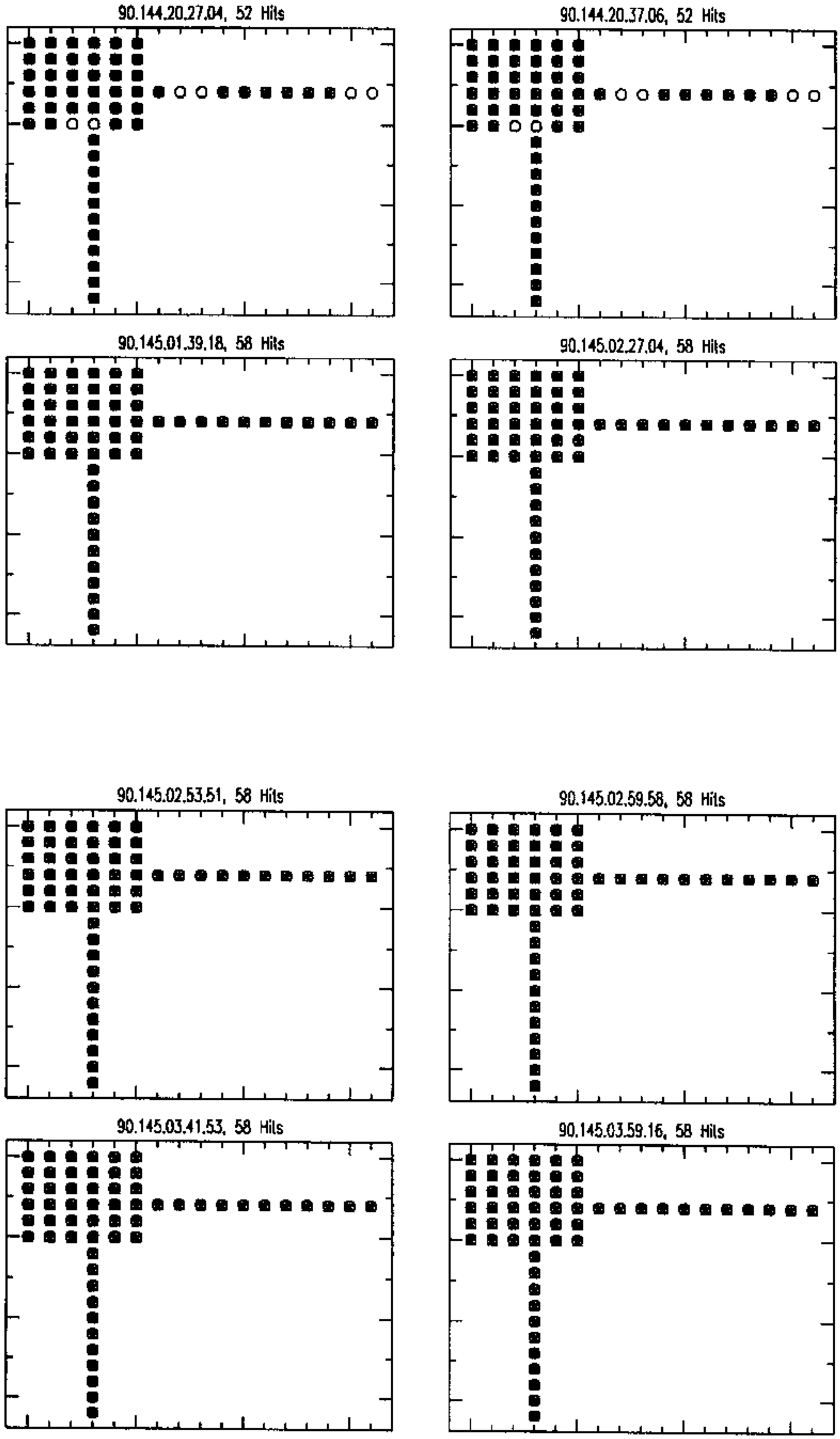

Figure 2: Hit Plot Example -- Open Circles indicates sites that did not record the event

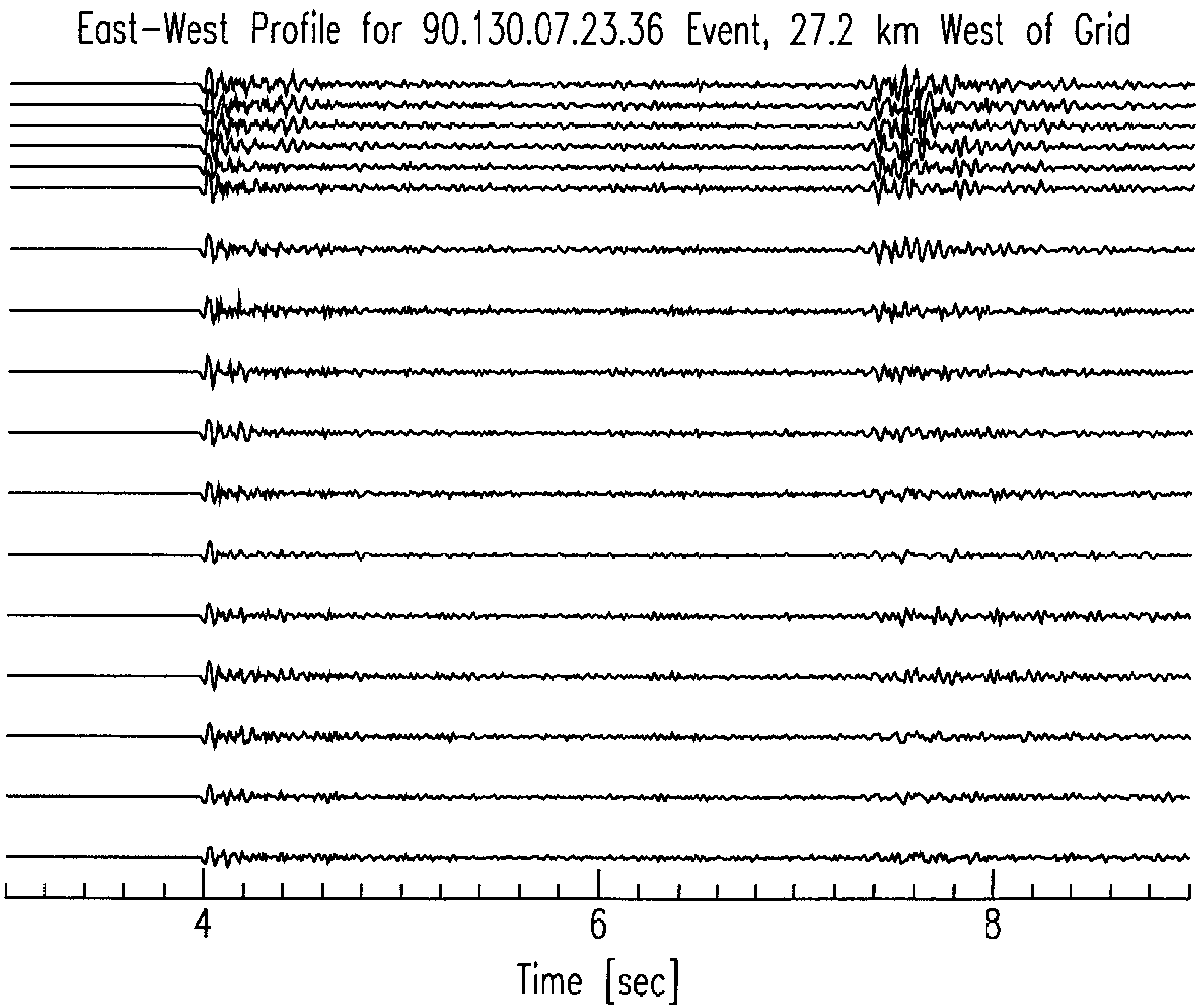

FIGURE 3: Record section for M=2.1, h= 15.3 km event due west of Grid, Vertical spacing approximates station spacing from west (top) to east (bottom)