Twin digital short period seismic Array Experiment at Stromboli Volcano.

Partecipant Institutions:

Dipartimento di Fisica, Università di Salerno
E. Del Pezzo*, Mario La Rocca, Simona Petrosino, Bernardo Grozea, Luigi Maritato, Gilberto Saccorotti

Dipartimento di Geofisica e Vulcanologia, Univ. Federico II - Napoli
Maria Simini

Istituto Andaluz de Geofisica - Univ. de Granada, Spain
Jesus Ibanez, Gerardo Alguacil, Enrique Carmona, Miguel Abril, Javier Almendros

C S I C. Museo Naccional de Ciencias Naturales de Madrid - Spain
Ramon Ortiz, Alicia Garcia

Osservatorio Vesuviano - Italy
Folco Pingue, Teodoro Esposito.

* E. Del Pezzo at Osservatorio Vesuviano since November 1,1997. He is the coordinator of the Research Unit.

Abstract

Two small arrays composed by short period (1 Hz) digital seismic stations, with an aperture of approximately 400 meters, were set up at Stromboli volcano (one at semaforo Labronzo, the other at Ginostra-Timpone del Fuoco) with the purpose of the spatial location of the high frequency source of the explosion quakes.

About 75 explosion-quakes were recorded at both arrays, and constitute the available data base.

We have planned to apply the zero-lag cross-correlation technique to the whole data set in order to obtain back-azimuth and apparent slowness of the coherent seismic phases. A preliminary analysis for both arrays show that the predominant back-azimuth for the first phase is oriented in the direction of , but not strictly coincident to, the crater area. Moreover some back-scattered arrivals are quite evident in the seismogram.

Introduction

Many experiments, carried out on Stromboli Volcano since 1973, demonstrated that explosive volcanic activity of Stromboli is strictly linked to the generation of the seismic activity. This last is very regular, with an occurrence rate of about 10 quakes per hour, showing a peculiar spectral shape. A persistent sustained tremor is moreover recorded on the seismic traces, whose spectra show a strong similarity with the spectra of the quakes.(Del Pezzo et al.,1974; Ntepe and Dorel, 1994; Ripepe and Brown,1993; Chouet et al.,1997)

One of the goals to be achieved is the definition of the physical model describing the source mechanics of the Stromboli's quakes. To reach this results the knowledge of the spatial extent of the source is an important step. Chouet et al.,1997, using a small aperture array of short period seismometers deployed on the northern flank at 1.7 Km distance from the active vents, have indicated that the preferred direction of the wave vector incoming to the array from the source is strictly coincident with the back-azimuth of the active vents. Moreover frequency slowness analysis, applied to the whole seismogram, shows that the back-azimuth from the active vents is a preferred direction also for the wave-packets arriving later than the first pulse. Array analysis also evinces scattering phenomena, generated by the most important structural and topographical irregularities, as for example the Sciara del Fuoco.

The present experiment has been carried out with the main aim to better constraint the source locations obtained by Chouet et al.,1997 and Saccorotti et al.,1998, who used a single array located at Labronzo site, on the northern flank of Stromboli. We deployed two arrays: the first, located at the old parossistic cone of Timpone del Fuoco, near Ginostra village; the second, located at Labronzo , approximately in the same site of the array described by Chouet et al.,1997 (fig.1).

Field Instruments

We used a PC based data logger to record data. This instrument was designed by R. Ortiz and G. Alguacil, and described in Olmedillas and Ortiz, 1990 and in Del Pezzo et al.,1997. In this report we give only general information about the instruments, while the details about the electronic schemes can be found in Olmedillas and Ortiz, 1990.

Seismic signals are amplified, then sampled with a 16 bits A/D converter, anti-alias filtered and stored on the hard disk of a portable PC. Timing is obtained with a GPS antenna connected with each data logger. Each data logger can record up to 8 channels.

The array located at Labronzo site (Fig. 2) is equipped with Mark L15, 4.5 Hz natural frequency sensors, electronically extended to 1 Hz. Four data loggers were used at Labronzo site, for a total of 32 channels. Each sensor was cased, together with the amplifier, and the circuit for the dynamic extension, in a small aluminum waterproof box. This box is cable connected to the anti-alias filter and the A-D converter, cased together with the GPS control circuit in a plastic box (the acquisition system box). The GPS time information is introduced into the PC via parallel port, while the data stream is introduced through the serial port.

The array located at Ginostra-Timpone del Fuoco Fig. 3) is equipped with MARK L4-C seismometers having natural frequency of 1 Hz. The amplified signal is transmitted via cable to the acquisition system box. The Ginostra array consisted of three data loggers, for a total number of 24 active channels.

The trigger algorithm (the usual LTA/STA) was used with the option that the recording is active when all the station of each subarray overpass the trigger parameter. Since each data logger was independent from all the others, it occurred that some events were recorded only by a part of the stations composing the array. The Sampling rate was fixed at 200 samples/s for each data logger in both sites.

Sensor were installed in approximately 50 cm deep holes, and then buried; This procedure was used in order to reduce the noise induced by the usually strongly blowing winds.

After the configuration was obtained, measuring preliminary the inter-sensor distances with a measuring strip and the orientation with a compass, the final coordinates were measured with differential GPS positioning, obtaining a precision of less than 10 cm.

The altitude differences among the sensors is less than 40 meters for both sites, and both the arrays were positioned at almost the same altitude (a.s.l.). The maximum aperture is more than 300 m for both arrays. The ratio between aperture and maximum altitude difference permits us to assume in first approximation a planar geometry.

Two 3-D sensors at Labronzo and three 3-D at Ginostra were deployed (see fig. 2 and 3). The direction of the sensors (N-S, E-W) was set up using a compass. Coordinates are reported in tab. 1.

Field Operation and Data recording

Normal field operation consisted in: diary battery change (each data logger was powered by two car batteries of 45 Ah), diary data transfer from the acquisition PC to a field portable PC (in average for each data logger about 70 Mb were recorded), diary general check of the instruments.

Data are multiplexed and recorded at each 8-channel data logger in the IAG (Instituto Andaluz de Geofisica) format (Guirao, 1989, Ph D. Thesis, Univ. de Granada). For each quake and data logger an header file and a data file are created; the header file is written in ASCII with the extension ".dat", and contain the information about date and time of the first sample, the station name, the maximum amplitude (in counts) for each station, the duration (in sample number), the corner frequency of the anti-alias filter and the triggering parameters. The data file is written in INTEGER*2 binary and the data are multiplexed in the following way: the first line contains the first sample for each channel, the second line contains the second sample and so on. The file name containing the multiplexed 8-channel data is composed by 8 characters, the first 3 representing the Julian day, the other 4 the hours and minutes of the day (GPS time). In table 2 the list of the 75 quakes recorded at a minimum of 7 subarray is reported. Data recorded during our experiment amount to a total of 1423 Mb. Once the data were collected they were visualized on the computer screen by using the graphical PICFASE package, used normally in the IAG at Granada University, in order to check the data quality and to disregard the false triggers. Pre-analysis, consisting in filtering, phase picking and zooming, is also implemented in PICFASE, allowing a fast data selection. An example of the data viewed by PICFASE is shown in fig. 4.

Most of the recorded events are explosion quakes, as can be easily seen by a fast comparison between the waveforms recorded in the present experiment and those studied in the past by several researchers.

Aim of the experiment

The first aim of the present experiment is to locate the sources of the recorded explosion quakes. The twin array will allow us to obtain two separate estimates of back-azimuth and apparent slowness of the coherent phases composing the seismogram. The intersection between the two estimated back-azimuth directions for the first arrival phase will estimate the epicenter of the source. The location of the sources of the secondary phases could give a location of the main scatterers: interesting will be the check of the hypothesis made by Chouet et al.,1997, that the Sciara del Fuoco re-focuses the wave energy produced at the source.

Another purpose is to obtain a velocity model of the shallow portion of Timpone del Fuoco, where the array equipped with MARK L4-C has been set up. We have planned to apply the techniques developed by Hermann (1987) and widely used at different scales to invert the dispersion curves for the corresponding velocity models. A first example is reported in Petrosino (1997) and in Del Pezzo et al.,1998 for the Labronzo zone. The results show that the techniques of Hermann give results similar to those obtained by using the stochastic method of Aki, 1957 applied by Chouet et al.,1997 at the same zone. Directly related to this study we wish apply the same technique to the tremor data collected in Ginostra site.

Preliminary Results

The zero lag cross-correlation analysis (Del Pezzo et al.,1997) has been applied to a selected subset of the available data. The selection was carried out on the base of the best signal to noise ratio and applied to the set of events which were recorded at both the arrays. Results of the cross-correlation method applied to 0.5 seconds of signal band pass filtered in the 1 - 20 Hz frequency band for the Labronzo and Ginostra site are shown in fig. 5 and 6 respectively. The zero-lag solutions for both the arrays locate the source North-westward of the crater area (Fig. 7). This result, that needs to be checked with the whole set of data, is in agreement with that obtained by Del Pezzo et al., 1987 using particle motion patterns. Chouet et al., 1997, using a single array located at Labronzo site, near the site of selected for the present work, find comparable results (see fig. 10 of their paper, where a rose diagram centered at the array site shows that part of the back-azimuths are direct to a zone outside the crater area).

Fourier Spectra (Fig.8) of the explosion quakes confirm that the spectral composition is mainly peaked at 2, 3 and 4 Hz, as the previous analyses have shown.

Discussion and Conclusions

The twin array configuration can be usefully applied to the Stromboli's data from explosion quakes in order to better constrain the source location. The preliminary results confirm the possibility that the source is not strictly coincident with the crater area. The next analyses will be:

1 - Application of the cross-correlation analysis to all the data set in order to confirm the preliminary result

2 - Application of the Bayes theorem to the statistics of the explosion source location, in order to constrain the area with highest probability of event occurrence

3 - Application of the dispersion wave analysis to the data from Ginostra array, in order to obtain a velocity model of the western flank of the Stromboli volcano

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Figure Captions

Fig. 1 - Map of Stromboli Island. dots show the station locations.
Fig. 2 - Array set up at Semaforo Labronzo. Cartesian coordinates are referenced at an arbitrary origin. Sensor latitude a.s.l. is also shown in the S-N and W-E projections.
Fig. 3 - The same of figure 1 for Ginostra site.
Fig. 4 - An example of data recording at subarray E for event 2570027
Fig. 5 - Zero-lag crosscorrelation analysis for Labronzo array.The analysis is carried out around the visually determined first onset. The first two windows sample the pre-event tremor, while the last two (below in the figure) sample the Explosion quake . Each window start at the sample # indicated on the top of each panel, sliding at each step by 50 points. Each window lasts 100 points, corresponding to 0.5 seconds. The last two windows show a back-azimuth of 206° North and an apparent velocity of 1.86 Km/s
Fig. 6 - The same of figure 5 for Ginostra site. The obtained back-azimuth is 77°North and the apparent velocity is 0.93 Km/s
Fig. 7 The central dot of the grey area is the solution for the quake used as example, obtained from the intersection of the array solution from both sites. The uncertainty area is represented by the grey color
Fig.8 Fourier spectrum of event 2570027 recorded at Ginostra array. The plot shows an array averaged spectrum (18 stations)

Table captions

Tab. 1 - Station coordinates (latitude and longitude, elevation)
Tab. 2 - List of the events which triggered both the arrays.

Table 1

Station Coordinates

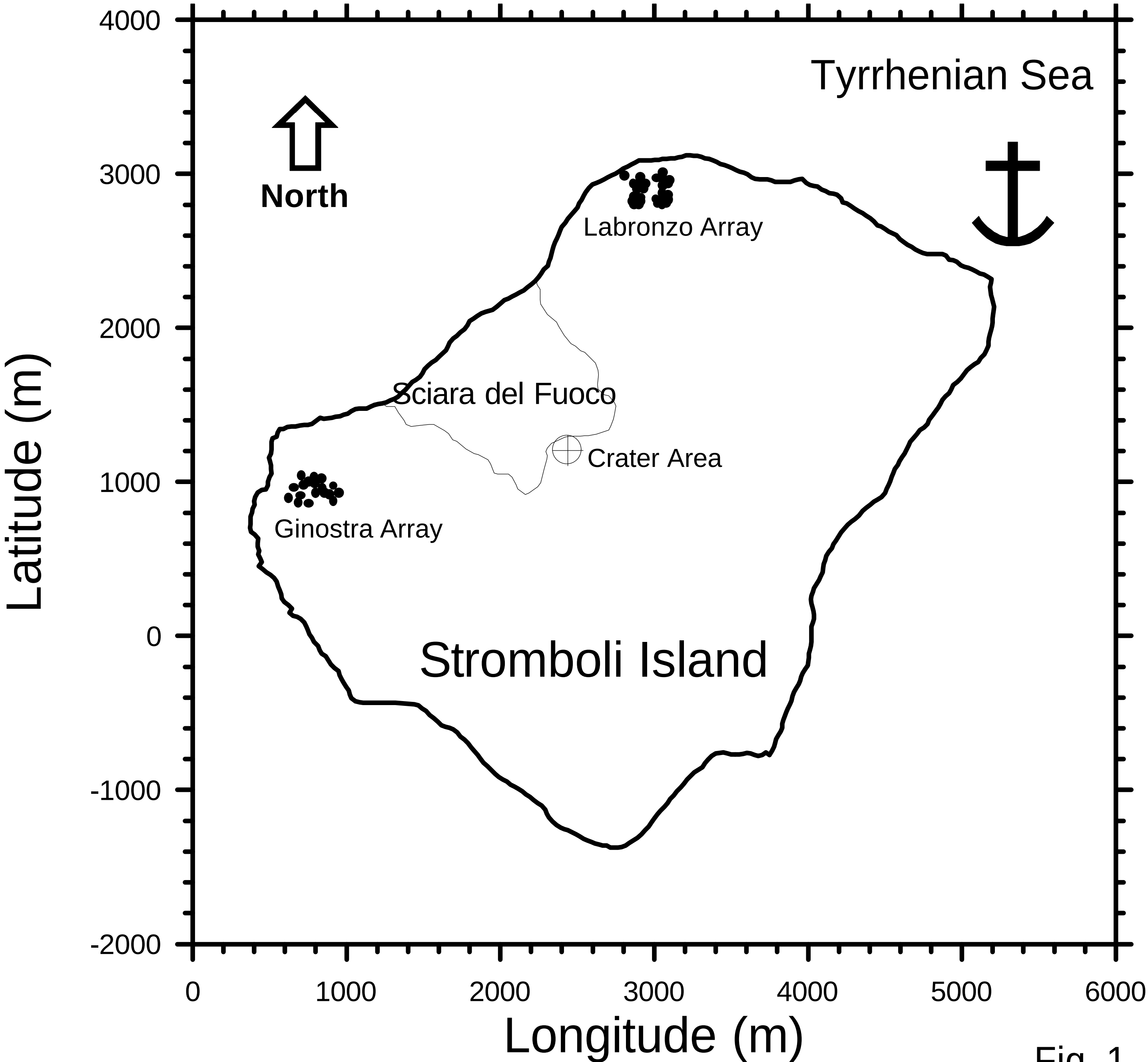
"station"	"X(m)"	"Y(m)"	"Z(m)"
"A0"	3056.7	2829.5	172.7
"A1"	3055.7	2796.5	182.4
"A2"	3026.8	2803.4	178.5
"A3"	3014.8	2834.1	169.2
"A4"	3057.1	2873.9	161.7
"A5"	3089	2859.1	164.5
"A6"	3097.1	2831.2	170.3
"A7"	3082.6	2803.7	180.1
"B0"	2907	2937.3	147.6
"B1"	2898.1	2896.5	153.3
"B2"	2869.1	2936.5	149.6
"B3"	2917.5	2971.5	144.4
"B4"	2948.1	2930	143.8
"B5"	2934.7	2904.4	149.6
"C0"	3064.1	2962.5	145.1
"C1"	3058.8	2924	153.5
"C2"	3017.8	2968.3	142.2
"C3"	3063.1	3005.4	138.9
"C4"	3100.8	2954.3	144.4
"C5"	3091.3	2931.5	151.8
"D0"	2888.9	2824.1	172.4
"D1"	2876.9	2794.9	178.8
"D2"	2864.5	2819.3	170.9
"D3"	2872.9	2847.4	162.8
"D4"	2890.3	2853.3	161.9
"D5"	2916.3	2845	164.2
"D6"	2918.1	2821.3	171.3
"D7"	2908.1	2798.2	178.3
"E1"	892.7	914.9	174.7
"E8"	859	922.2	168.1
"E7"	844.1	955.9	165.2
"E4"	917.1	872.1	173.5
"E6"	917.1	969.1	183.6
"E5"	955.7	924.4	193.7
"F4"	701.7	908.4	163.4
"F1"	627.8	893	171
"F7"	664.3	960.8	162.7
"F8"	730	978.4	156.7
"F5"	758.3	855.9	157.5
"F6"	688.1	859.5	163.8
"G8"	794	1031.5	151.7
"G1"	805.8	923.2	160.3
"G6"	799.2	985.7	158
"G5"	758.3	998.5	154.8
"G7"	838.6	1020.8	156.6
"G4"	710.3	1038.9	152.5
"SEMAFORO"	2810.9	2986.6	145.6
"B0"	2907	2937.3	147.6
"C0"	3064.1	2962.5	145.1
"E1"	892.7	914.9	174.7
"F1"	627.8	893	171
"G1"	805.8	923.2	160.3

Table 2

List of events triggering all the sub-arrays (ABCDEFG).

---- indicate low average signal to noise ratio

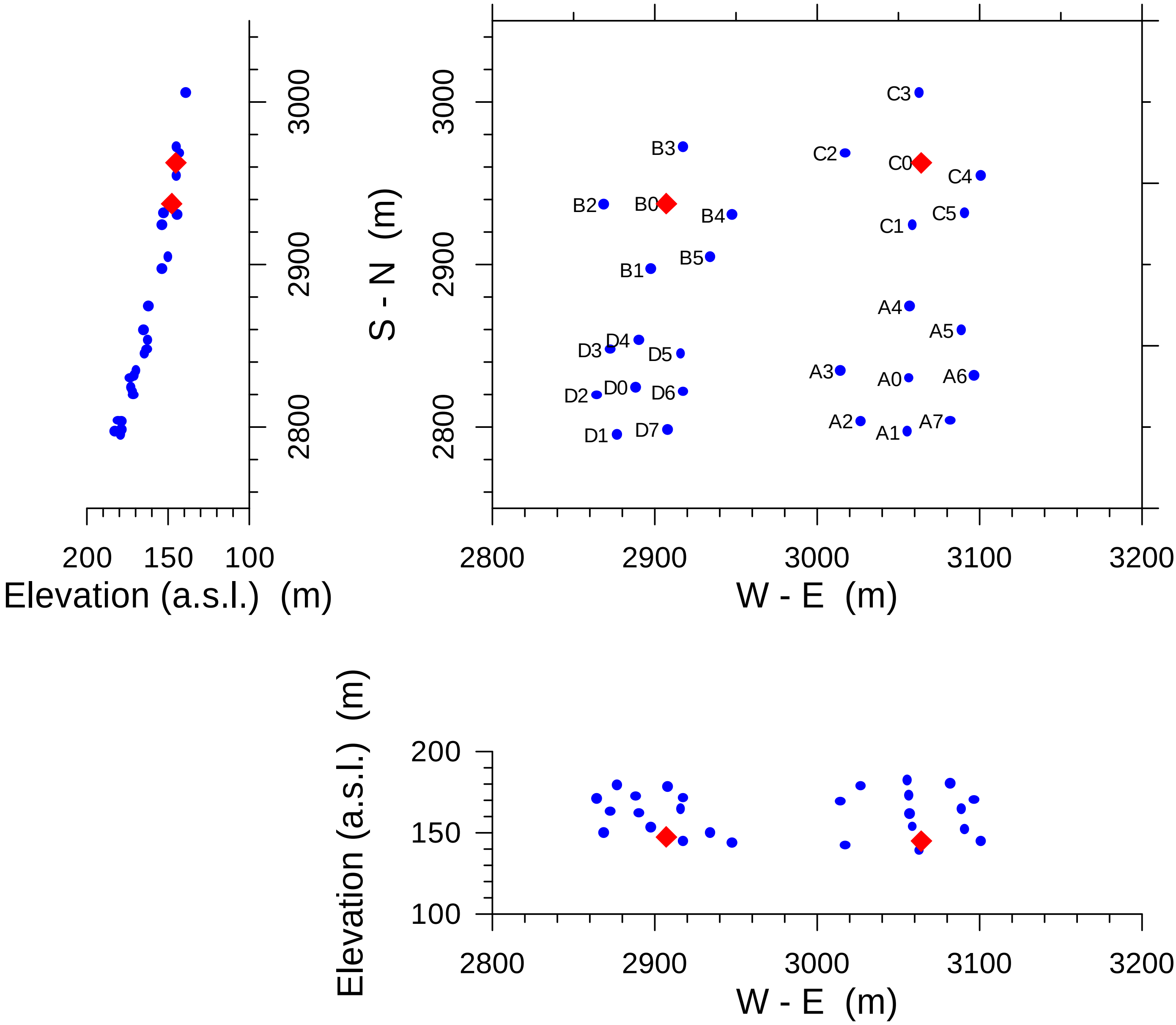
1) 2561544
2) 2561557
3) 2561603
4) 2561608
5) 2561617-8
6) 2561620
7) 2561647
8) 2561732
9) 2561808
10) 2561826
11) 2561830
12) 2561901
13) 2561904
14) 2561909
15) 2561929
16) 2561954 ***
17) 2562001
18) 2562004-5
19) 2562020-1
20) 2562042-3
21) 2562046
22) 2562055-6
23) 2562129
24) 2562244
25) 2562256 -----
26) 2562316-7
27) 2562334
28) 2562343
29) 2562353
30) 2562358 -----
31) 2570001 -----
32) 2570018 -----
33) 2570027
34) 2570035 -----
35) 2570046
36) 2570055 -----
37) 2570100 -----
38) 2570110
39) 2570120
40) 2570131 -----
41) 2570249
42) 2570256 -----
43) 2570300
44) 2570315
45) 2570332
46) 2570409
47) 2571714
48) 2571847
49) 2571851-2
50) 2571856
51) 2571902-3
52) 2571927
53) 2571942
54) 2572019
55) 2572036-7
56) 2572116
57) 2572137
58) 2572157
59) 2572206
60) 2572231
61) 2572244
62) 2572256
63) 2572320
64) 2572326
65) 2572350
66) 2580042
67) 2580049
68) 2580106
69) 2580122
70) 2580127
71) 2580141
72) 2580213
73) 2580239
74) 2580244-5
75) 2580251
76) 2580532
77) 2581918
78) 2582041
79) 2582252 -----
80) 2590014



Tyrrhenian Sea
North
Labronzo Array
Sciara del Fuoco
Crater Area
Ginostra Array
Stromboli Island
Latitude (m)
Longitude (m)
4000
3000
2000
1000
0
-1000
-2000
0
1000
2000
3000
4000
5000
6000

Fig. 1

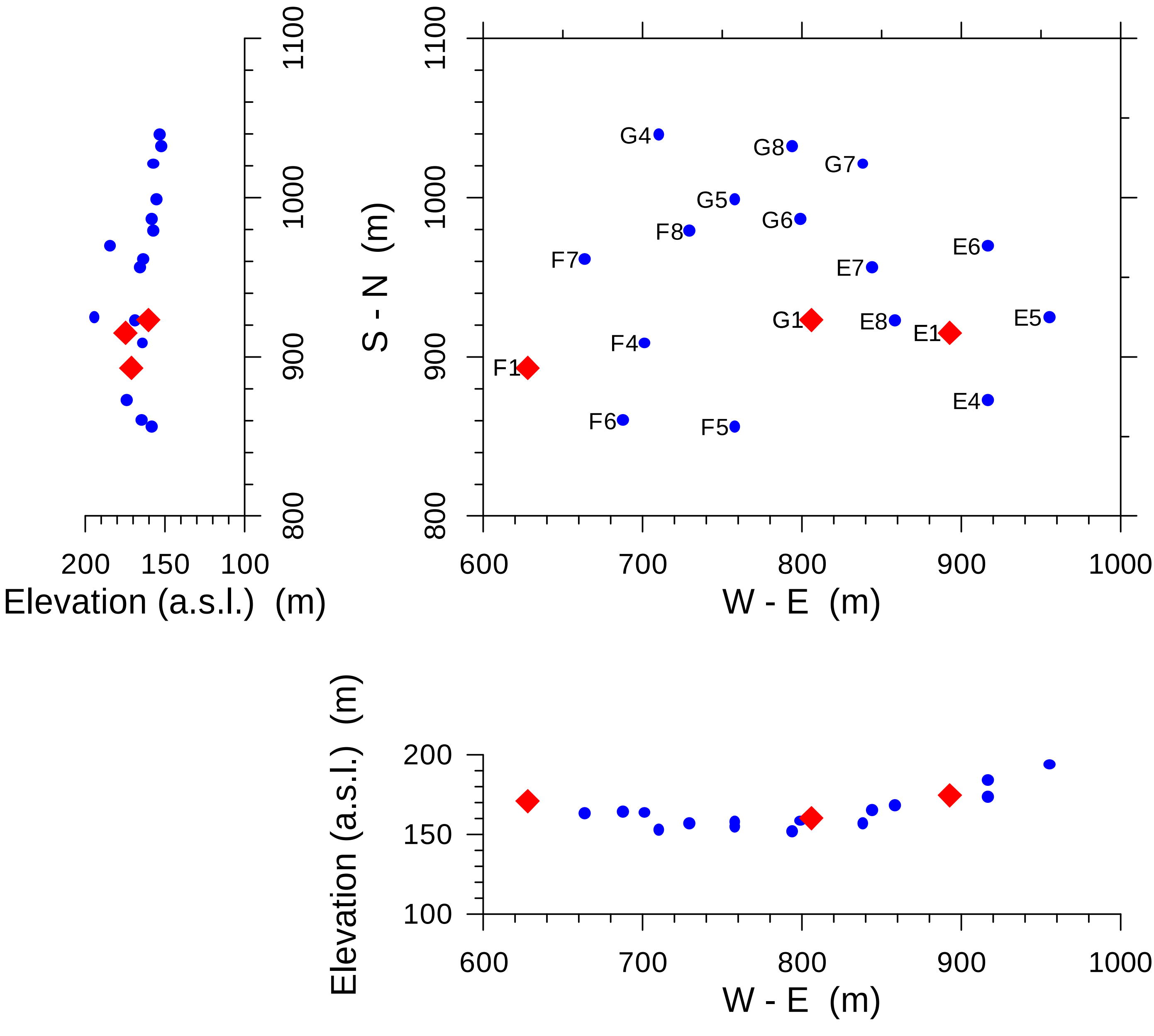
Labronzo Array Configuration



Three component sensors are shown in red

Fig. 2

Ginostra Array Configuration



Three component sensors are shown in red

Fig. 3

Event # 2580141 recorded at Ginostra array

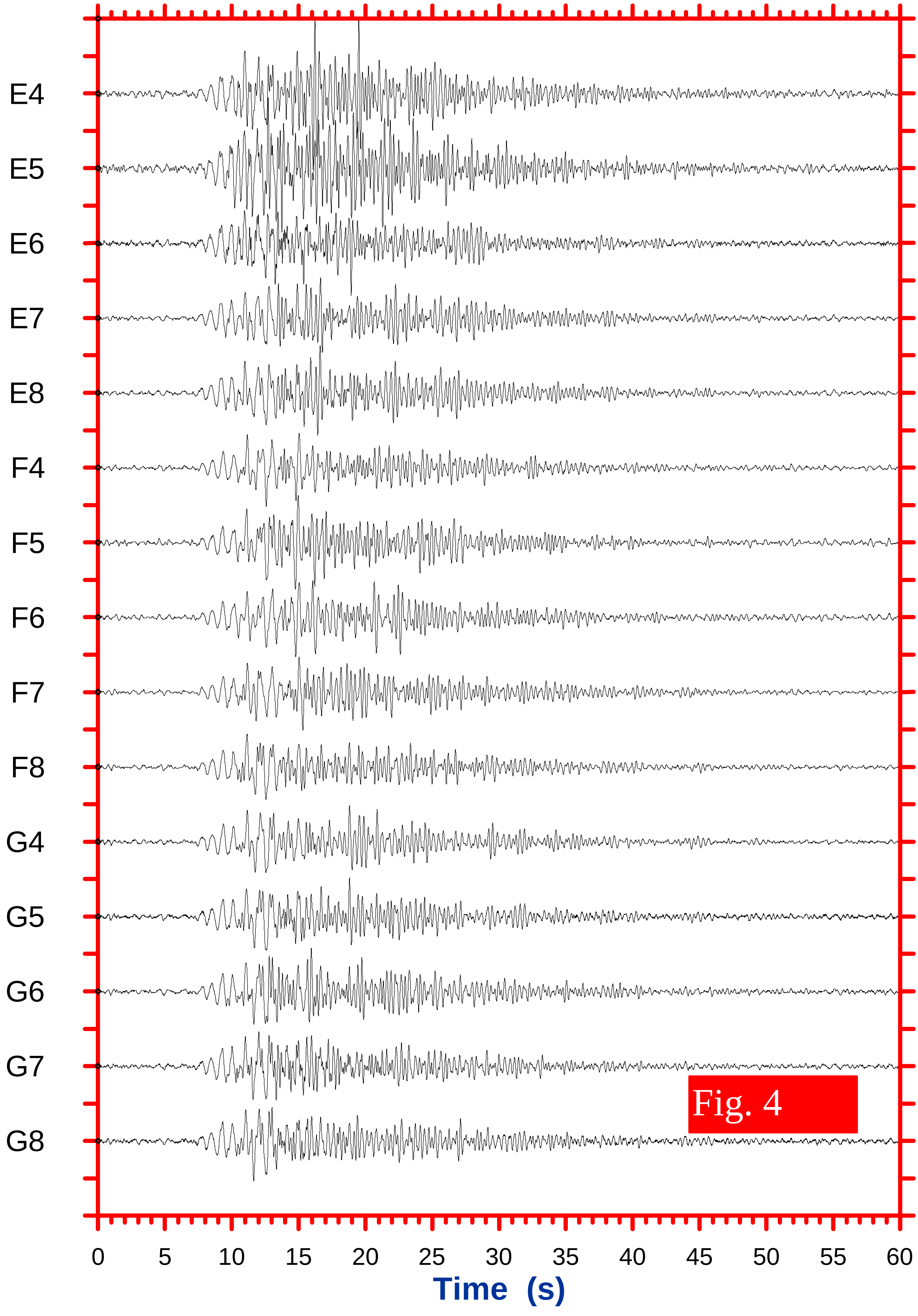
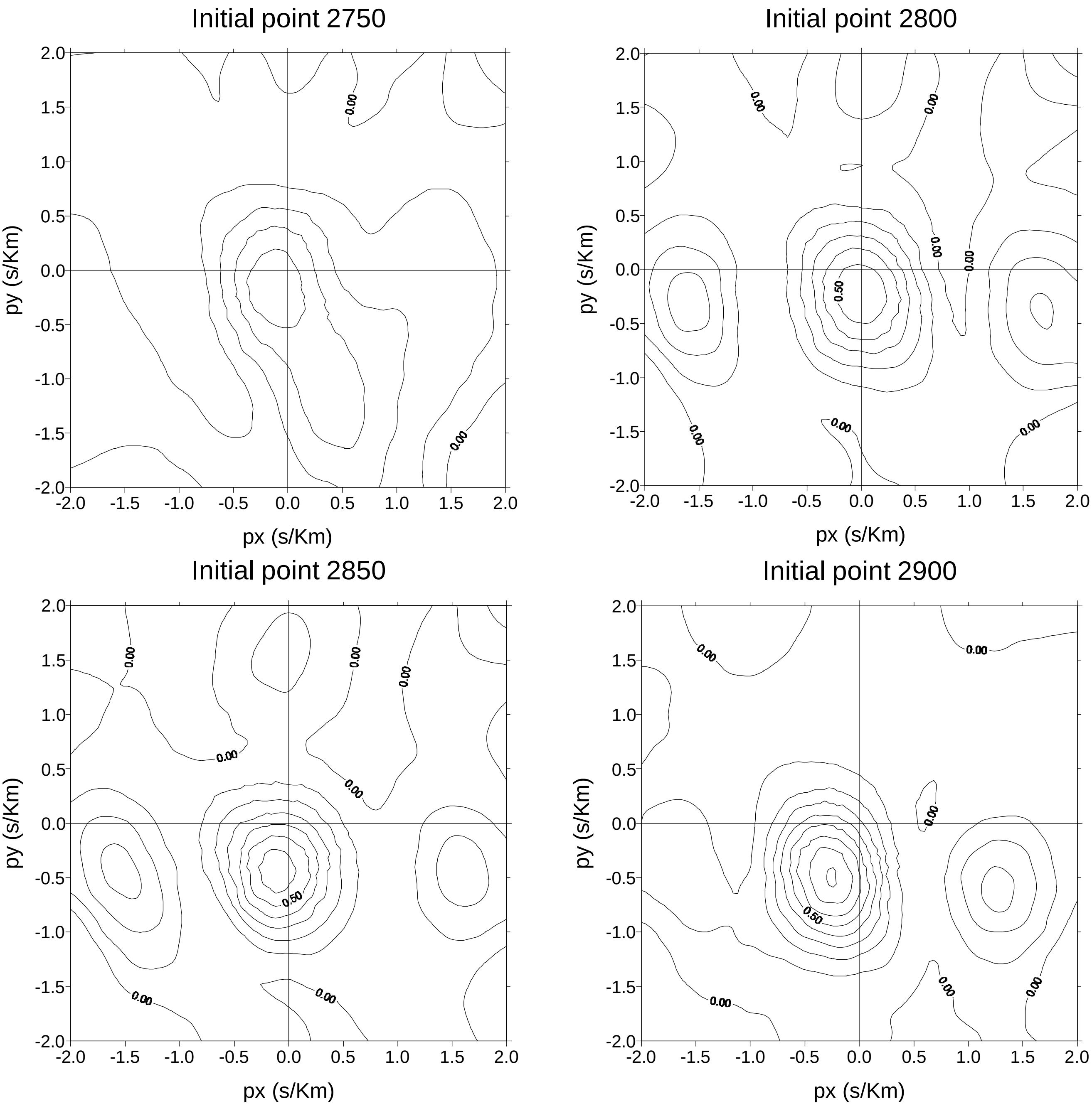


Fig. 4

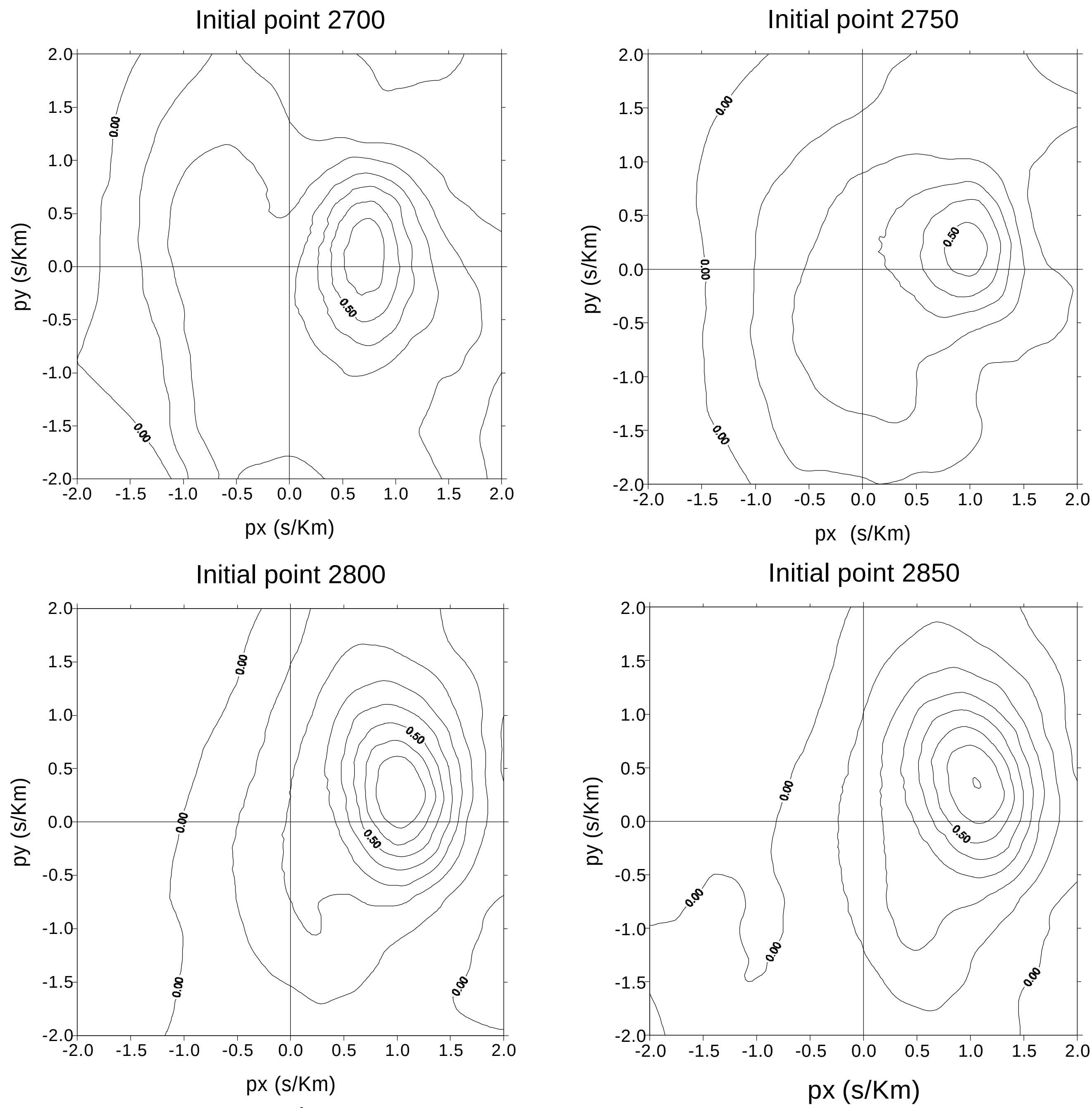
2570027 array ABCD, 100 pt, 28 canals



Va = 1.86 Km/s
backazimuth = 206°

Fig. 5

2570027 array EFG, 100 pt, 18 stations



Va = 0.93 Km/s
backazimuth = 77°

Fig 6

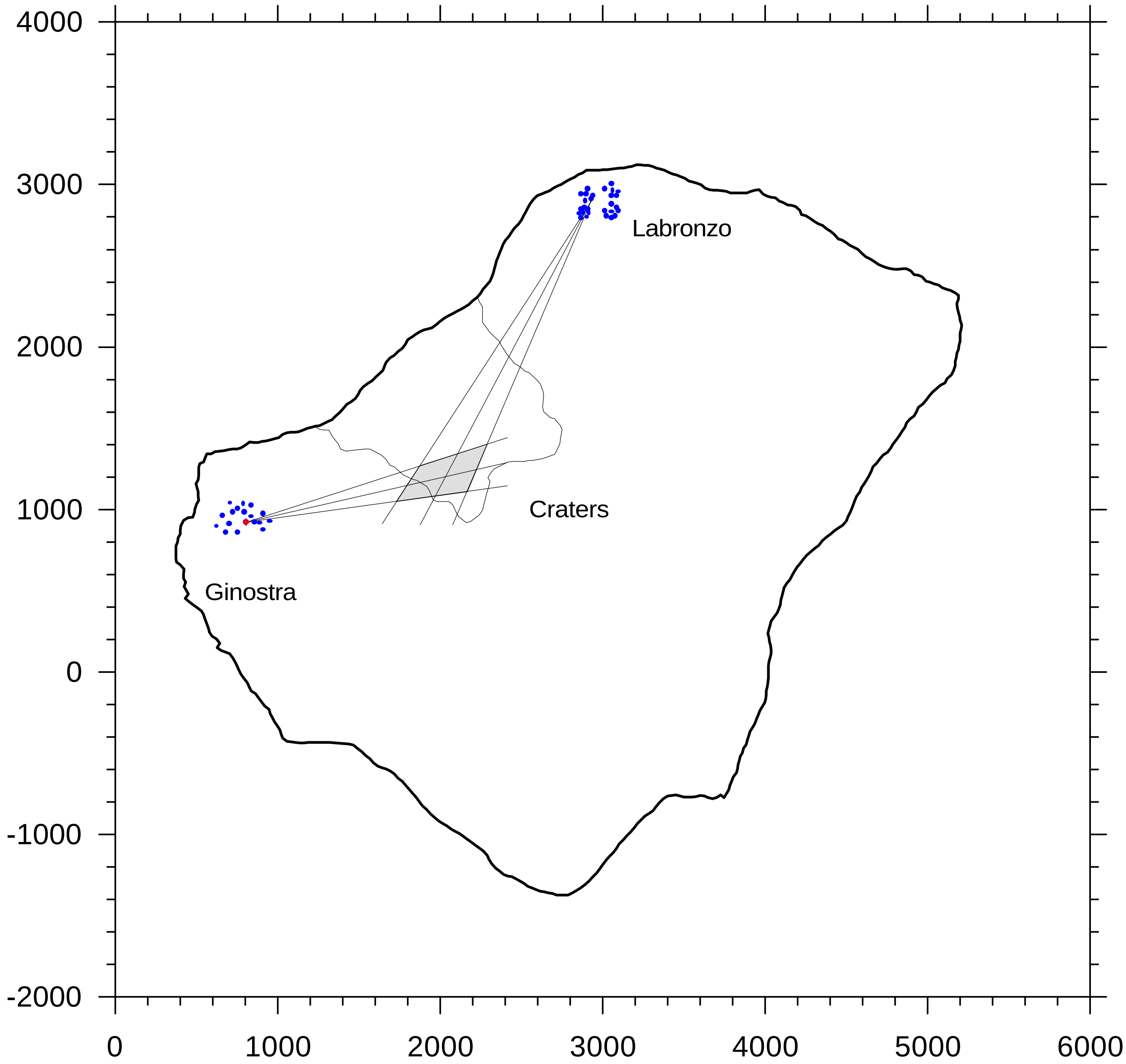
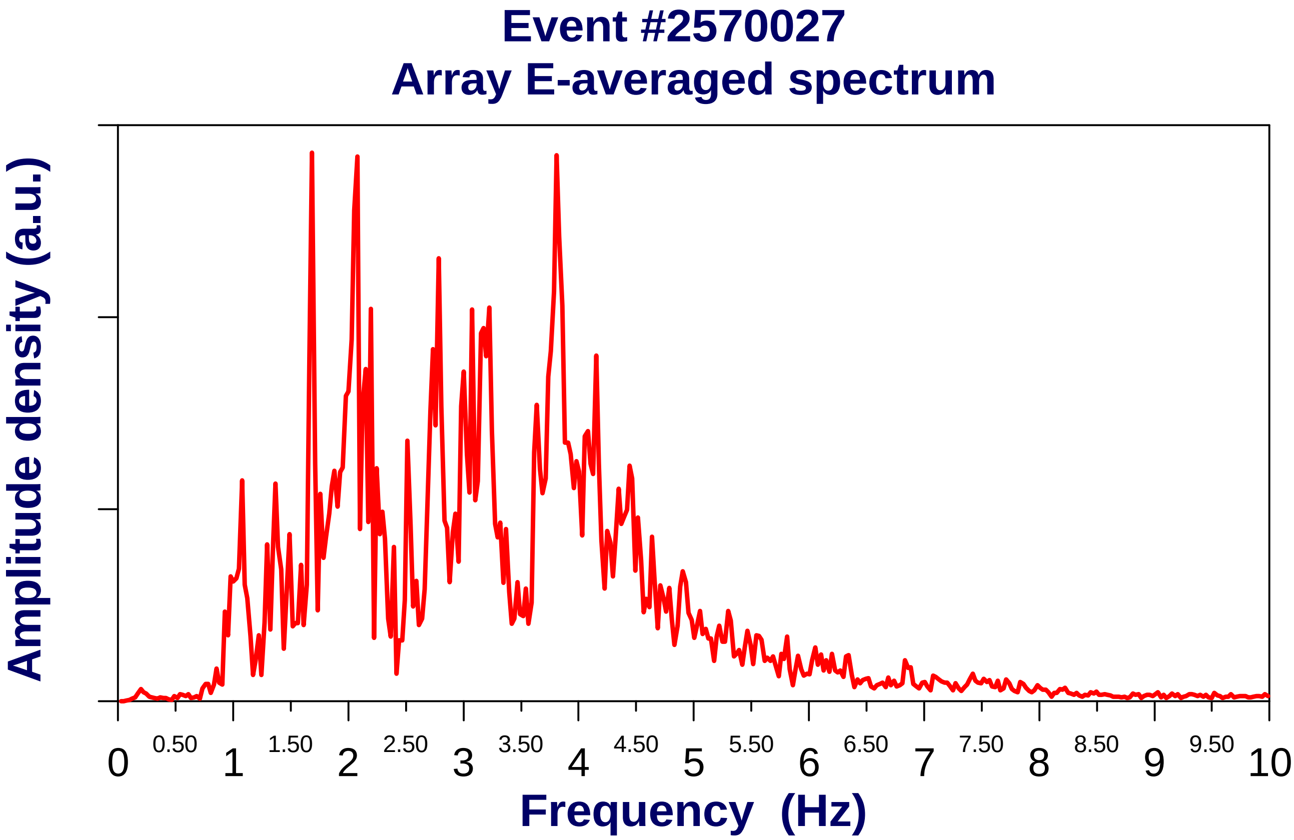

4000
3000
2000
1000
0
-1000
-2000
0
1000
2000
3000
4000
5000
6000
Labronzo
Craters
Ginostra

Fig. 7



Event #2570027
Array E-averaged spectrum
Amplitude density (a.u.)
0
0.50
1
1.50
2
2.50
3
3.50
4
4.50
5
5.50
6
6.50
7
7.50
8
8.50
9
9.50
10
Frequency (Hz)

Fig. 8